University of Alberta

# Predicting and Evaluating Construction Trades Foremen Performance: Fuzzy Logic Approach

By

**Cesar Augusto Poveda** ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

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Dr. Aminah Robinson Fayek

Dr. Yasser Mohamed

Dr. Peter Flynn

*This thesis is dedicated to my family*

# Abstract

This research studies the use of fuzzy expert system to predict and evaluate the construction trade foremen performance. Supported by the job description developed by the Construction Owners Association of Alberta and an extensive literature review, the prediction and evaluation of performance was divided in six categories.

Factors impacting the construction trade foreman performance were identified. A fuzzy expert system consist of membership functions, a fuzzy rule base containing If-Then rules, a fuzzy inference system, and a defuzzification module, was generated for the model. The model was validated and tested (e.g., sensitivity analysis) to improve its accuracy, and validated using data collected through self-responded questionnaires. The model presented high numeric accuracy.

The study demonstrates the use of fuzzy expert system in predicting and evaluating the construction trades foreman performance, given limited data and a large number of input factors. It also opened new horizons in this area of research. To explore new possibilities in measuring performance some recommendations were made and should be considered in near future research.

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# CHAPTER 1 INTRODUCTION

## 1.1 Background and Problem Statement.

As foremen are a critical link between management and the workforce, a considerable number of studies have been conducted to improve their performance. In the construction industry the foreman manages a substantial quantity of work and information; it is also expected that the foreman participates in planning, defining work, communicating with their crew members, and also motivating them. To acknowledge and help them in their daily tasks some techniques have been proposed and others are still under review. Finding a good foreman with high quality performance begins when the individual is an apprentice influenced by other workers and his/her own foreman. Helping the foreman to improve his/her performance starts with proper training and continues in his daily tasks.

In order to develop an innovative methodology to help foremen improve their performance and management to identify valuable workers (foreman), the present study proposes a methodology to measure, evaluate, and manage the performance of construction trades foremen (i.e., front-line supervisors) using fuzzy logic theory. The use of this tool will bring benefits such as evaluation of foreman's performance, identification of gaps in their performance, requisition of training, differentiation of gaps within the assessment groups (foreman, supervisors and peers, and crew members), recognition of difficulties to performance inherent in the given project and/or company context, and measurement of improvements in performance during a given period of time.

Each one of the factors that impact and influence the performance of a foreman needs to be discussed separately and analyzed depending on the atmosphere in which the worker is involved, the characteristics of the crew, the company rules, and the particular environment of the job. In order to succeed with the development of the tool proposed, factors identified and correlated with the foreman's performance, the training needed and areas where the foreman needs to improve have to be recognized.

The training would be the first area to analyze in the process to improve the foreman's performance; however, some other areas must be identified throughout the time the foreman is in the labour force. The foreman must be productive to be successful, and to help him in this task, intrinsic characteristics of productivity and also some factors that affect his performance need to be identified. Some of the areas have been covered in the present literature review focusing on those that apply to the study and are related to develop the methodology proposed. In the following sections a brief background of the topic will be discussed; although there has not been enough research on this topic in Alberta some attempts have been developed (Bantrel Constructors and Construction Owners Association of Alberta).

Even though some techniques are available to measure the performance of the foremen, there are some challenges present in this area of research. The measurements to evaluate performance are conditioned to many other factors similar somehow to the ones that influence the performance of the foreman. Data collection techniques and performance evaluation methodologies have been matters of previous studies, giving to future researches a guideline to continue developing an improved method to measure the foreman's performance and identifying how to help him to enhance better results.

Although there could be clear identification of the methodology to evaluate performance, imprecision and vagueness are also present as natural phenomenon that could occur in any human conceptualization activity. The difficult task in measuring the performance of any individual in an engineering organization is related to the fact that it is a series of complex activities to find accurate variables that are suitable to evaluate performance. Even though the variables to evaluate the performance can be identified, the next step would be quantifying the contributions of these variables on the inputs and the outputs in the performance evaluation process. Traditional methods of measuring performance, such as simplistic correlation between measurements of productivity projected in a period of time and a particular individual, have obvious limitations because they could leave some factors out of the equation; company commitment in improving the performance of its workers, subjective evaluation by members of the organization (surveys within the company to evaluate performance), and training received to increase performance. Subsequently, a new method needs to be found to evaluate the performance of this critical link between workforce and management (foreman) in order to correlate the subjective and objective factors involved in the process.

So far, fuzzy set theory has not been used as extensively to evaluate the performance of individuals as researchers could expect. The approach of dealing with performance evaluation using linguistic terms could solve the problem of uncertainty and vagueness of predicting performance of an individual in any engineering organization. This thesis develops a new method of evaluating the performance of construction trades foremen for construction organizations based on the techniques of fuzzy set theory. We expect to prove that fuzzy set theory is the appropriate technique for this research area.

## 1.2 Purpose of the Study and Expected Contributions

The main objective of this research is to develop a fuzzy logic model for use in evaluating foreman's skill level.

In addition, this research also involves the following sub-objectives:

- To develop a methodology to evaluate the construction trades foreman's performance.
- To identify the factors that impact directly and/or indirectly the performance and to what degree they affect the construction trade foreman's performance on a daily basis.
- To develop a fuzzy logic model for use in predicting the construction trade foreman's skills level. Once the evaluation of the skill level has been accomplished, pre-existing information can be used to predict the skill level assessment of any individual.
- To evaluate the performance effectiveness of a construction foreman using the fuzzy logic model, and to translate numeric information into linguistic descriptors easy to understand by the users.
- To develop and test a new technique using subjective data as inputs and compare the outputs generated by the fuzzy logic model to support the subjective measures with more objective results (e.g. project control data).
- To create a model to make comparisons between assessment groups (foreman, supervisors and peers, and crew members) and identify performance gaps within the assessment groups for a construction trade foreman.

- To identify and measure the improvement of performance in each category of assessment (safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration) using the fuzzy logic technique, and also make comparisons between categories that identify areas of strength or weaknesses.

## 1.3 Expected Contributions

The research is expected to make contributions because of its attempts to:

- Use fuzzy logic theory for assessing performance prediction and evaluation, which will direct more attention to this area of research.
- Experiment with a new methodology for evaluating the performance of construction trades foremen, which involves subjective evaluation from three different assessment groups.
- Experiment with membership functions, defuzzification methods, and implication and aggregation methods to provide a reasoning framework for evaluating and/or predicting the foreman's skills level.
- Test the effectiveness of the fuzzy logic theory and to compare with statistical analysis methods used in previous studies on performance evaluation (Fayek and Poveda, 2008).

## 1.4 Research Methodology

The first step in this study involves a thorough literature review to identify the factors that affect the construction trades foreman, and to recognize the efforts already made in evaluating the performance of workers including numeric (statistical) and/or fuzzy logic theory applications.

As starting point the author used the construction trades foreman's position description developed by the Construction Owners Association of Alberta (COAA) that combined with the factors identified in the literature review helped to classify the categories (safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration) involved in the foreman's responsibility and duties. For rule base development purposes each category was divided into several sub-categories (i.e. input factors). Each set of factors evaluate each group assessment separately (i.e. intermediate output), and the combination of the three assessment groups evaluate the foreman's performance in each category. This structure allows separate evaluation of each category, and individual evaluations for each assessment group. This structured list of factors forms the basis of the model for predicting and evaluating the construction trades foreman's skills level.

A six month study on site including a two month survey with an industrial contractor in Alberta was conducted to obtain actual data. The data collected in the survey was also used for a project for the Construction Owners Association of Alberta to develop a "Skill Development Tool for Construction Trade Foreman." From this study a number of subjective linguistic factors were identified. These data were used to develop and test the fuzzy logic model, including membership functions, defuzzification methods, and implication and aggregation methods.

The first step in developing the fuzzy logic model was to create the membership functions. A preliminary series of membership functions were created for the inputs, intermediate outputs and overall output. To create the preliminary series of membership functions the author studied previous models used to evaluate performance (e.g. machines performance, design performance).

The rule base was developed using the objective data collected in previous stages of the study (e.g., survey). Once the rule base was completed and to give the model high reliability the accuracy of the system was tested.

Finally, a sensitivity analysis of the fuzzy logic model was conducted to test its sensitivity to fuzzy operations, implication and aggregation methods, and defuzzification methods. As a result, this sensitivity analysis helped to improve the model's accuracy and to optimize the percentage of error.

## 1.5 Thesis Organization

Chapter 2 contains a literature review, describing the application of fuzzy set theory in the construction industry. It also covers a description of previous research on performance evaluation and provides a complete description of construction trades foremen as an important link between the workforce and management.

Chapter 3 presents a description of the data collection process and illustrates the questionnaires used by the author in the study. It also presents the survey methodology and data processing procedure used in the study.

Chapter 4 describes the factors involved in the construction trades foreman's performance evaluation and explains the measures for each variable involved in the foreman's performance evaluation. It also contains a description of the structure of the fuzzy logic model and factors involved in the foreman's performance evaluation.

Chapter 5 describes how the membership functions were generated including assumptions and methods used in the fuzzy logic model. It also contains an entire description of how the fuzzy expert rules were develop and tested with data collected in the surveys, and describes the procedures used for generating fuzzy it-then rules.

Chapter 7 presents the case study, data set used in the validation, and sensitivity analysis results. This chapter also presents the results obtained in the validation process and sensitivity analysis of the fuzzy logic model.

Chapter 8 describes the conclusions of this research and recommendations for future development. The contributions and limitations confronted in the study are also included.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 Introduction

Due to the extensive literature found covering the topic of foreman performance, it is necessary to separate this topic into different sections to distinguish between studies that relate directly to the characteristics and/or performance of the foreman, and studies that relate to the use of fuzzy logic to evaluate the foreman's performance. Some of the topics covered in this chapter are: foremen training, the foreman as an apprentice (journeyman), characteristics of good foremen, scales to measure performance, the foremen's influence on performance, and application fuzzy logic in the process of evaluating performance. Each of the sections in this study cover the main points to succeed with the objectives of the study. For example, training is generally the main area to be improved upon in the case of poor foremen performance, however training may not be the only reason the foreman's performance is weak, and this is discussed in the following sections. But, how we identify good foremen or what characteristics they ought to have are questions that need to be answered if the performance is to be improved. Before giving a methodology to make better foremen, the existing methods need to be clarified.

Subsequent sections will address the most important topics that relate to the foreman's performance and how they impact it, which includes identifying what training foremen may need, what characteristics they should have, and more importantly how foremen impact on the performance of their crew members, and how their performance influences productivity. Last but not least, in order to measure the foreman performance an objective scale needed to be used; supported by previous studies the scale used in this research tried to measure the factors that affect the construction industry in Alberta, and supported the creation of the membership functions in the fuzzy logic model.

## 2.2 Background

Insufficient research has been developed on improving the performance of employees in the Albertan construction industry, especially in regards to foreman, and as each projects' work conditions vary due to specific characteristics such as budget considerations, weather conditions, and labour availability among other factors, exploring new ways of doing what has been done for decades is a challenge for the management team.

One of the existing techniques applied by construction companies in North America is the 360-Degree feedback technique, which is an appraisal technique in which a profile of the employee is gathered from different perspectives. The participation of subordinates, peers, colleagues from other departments, clients, business partners, and other business contacts of the employee is sought to provide as wide a range of feedback as possible, thus providing a complete image of the employee, and thereby providing the name of the technique as well. A pioneering company in applying the 360-Degree Feedback technique to improve performance in their employees was Bantrel Constructors Co. through its Department of Labour Relations.

Another program that has been used is Better SuperVision (Construction Labour Relations-Alberta, 2007), it is program designed to equip unionized construction supervisors with those leadership skills that help create a safe, productive and motivated workforce. It encourages ongoing communication and feedback between a Coach/mentor and a learner foreman to support the practical application, implementation and development of core supervisory skills.

Essentially, the 360 Degree technique (Bantrel Constructors Co, 2005) consists of a process that an employee is required to participate in after he or she has been appointed to a new position. Generally this review is done 30 days after the employee has been promoted. He or she will be evaluated in six different areas (safety, trades people, peers, labour relations, supervisor, construction management, see fig. 2-1), by the current supervisor, general foreman, superintendent, and the Environmental Health and Safety (EHS) representative in the company. The candidate will also be evaluated by randomly selected crew members.

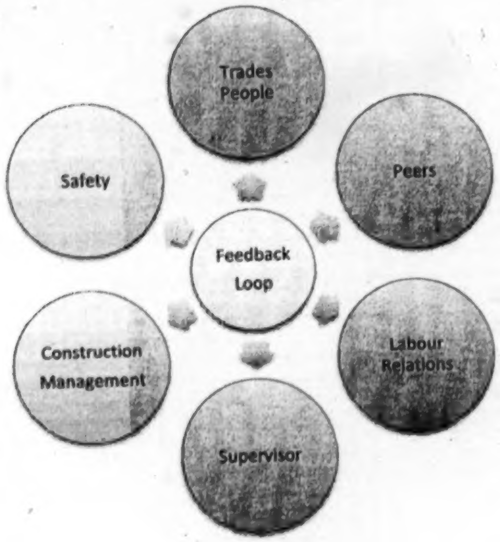


Figure 2-1: Areas of Evaluation – 360 Degree Feedback technique

However, the 360 Degree technique was not designed only for existing foremen, it was also designed for promotion consideration as well as continual improvement monitoring (Bantrel Constructors Co, 2005). Depending upon for which area the employee is being evaluated the people involved with the evaluation may have different questionnaires. For example, for a **consideration foreman** position (e.g., identification of potential foremen), the employee's current supervisor, general foreman, superintendent, and the Environmental Health and Safety (EHS) representative will be involved. For **promotion consideration**, crew members, the general foreman, the superintendent, the Environmental Health and Safety (HSE) representative, and labour relations will answer their respective questionnaires. For **continual improvement monitoring**, crew members, general foremen, superintendents, the Environmental Health and Safety (HSE) representative, and labour relations will help in this task.

Although this technique (e.g., 360 Degree) can be used for multiple purposes, there are some advantages and disadvantage that are important to mention. Advantages of the 360 Degree feedback review include a more complete assessment, from different perpectives, despite the subject nature of such an assessment. Consistency in the assessment may be improved by increasing the number of participants. The subjectivity may be reduced by adding objective measures of assessment suc as project controls datra (e.g., performance data). The 360 degree feedback provides an extensive range of feedback of the employee being evaluated, and the reviews assist management in having a more detailed, all encompassing appraisal of the employee. Disadvantages of the 360 Degree Feedback technique are that the time and effort needed for the review process is considerable, however, for a committed and motivated company, this disadvantage should not generally be a problem.

As part of the 360 Degree Feedback technique's process and to evaluate foremen performance, Bantrel Constructors Co. identified a number of responsibilities included in foremen's daily, weekly, and monthly duties. However, requiring foremen to be take responsibility for all these duties could lead to very high expectations. Even though the foremen's profile means that he or she is the front line supervisor, overloading them with too many responsibilities could result in poor performance, which can be reflected on the crew members. Although the findings by Bantrel Constructors Co. do not have a scientific basis, they provide valid information to ascertain where to search when it comes to foremen performance, productivity and time management, and in finding ways of putting the foremen back on site, and doing what they are supposed to do, which is supervise their crew members.

The Construction Owners Association of Alberta (COAA) created the construction trades foreman job description, shown in Appendix A, through its Supervisory Training and Qualifications Subcommittee, which includes responsibilities in six different categories, required knowledge, skills and attitudes, and qualifications (e.g., training, education level, and experience) as Figure 2-1 shows.

The main objective of the COAA Supervisory Training and Qualifications Subcommittee with their position description was to set an achievable performance standard for a foreman (front line supervisor) on construction sites in Alberta. Even though this is a general description for foreman responsibilities, it does not represent the duties and responsibilities that every foreman must perform in his/her daily tasks since each company has its own internal structure, and even within the company each section (department) may work independently.

The most important responsibilities of foremen according to the COAA's best practices developed by the Supervisory Training and Qualifications Subcommittee can be classified into six areas of safety, leadership and supervision, planning and scheduling, labour relations, quality control, and administration. Construction trade foremen should provide leadership, design work schedules, coordinate crew members, provide supervision, and ensure the safety and productivity of crews at the workplace. Also the foreman is considered key in the relation between the contractor, company, and client. Essentially, the foreman acts as a liaison between management and the client.

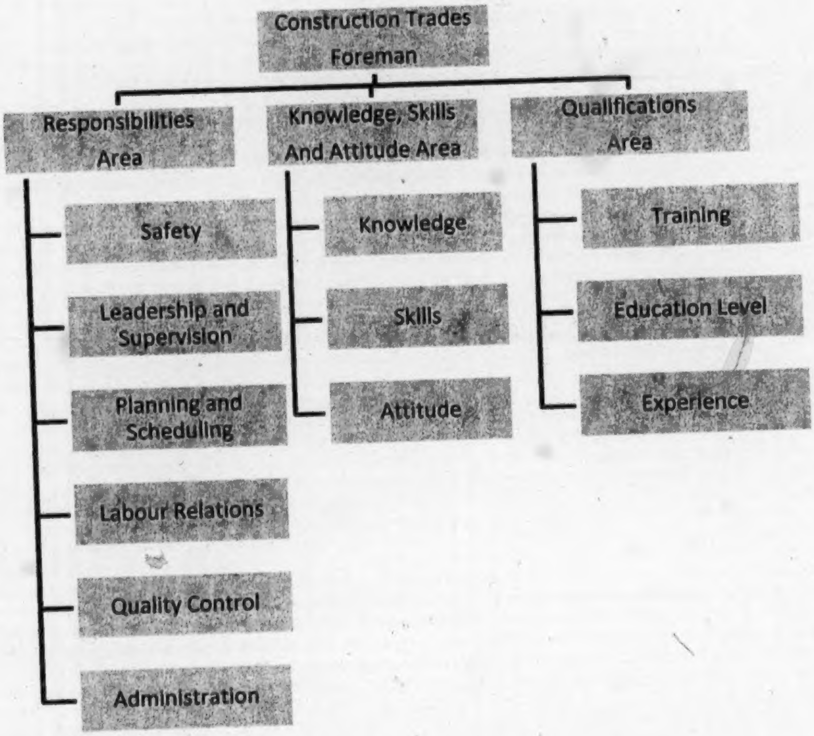

Construction Trades Foreman
Responsibilities Area
Knowledge, Skills And Attitude Area
Qualifications Area
Safety
Leadership and Supervision
Planning and Scheduling
Labour Relations
Quality Control
Administration
Knowledge
Skills
Attitude
Training
Education Level
Experience

Figure 2-2: Construction Trades Foreman Areas of Responsibilities

## 2.3 Foremen Training

In any company's success, the training of its workers plays an essential role. As foremen are the first line supervisors, and as those who are directly involved with the work force, their training needs to be designed according to their needs, duties, responsibilities, and company size and policies.

Warr and Bird (1967) conducted a study related to the training needs of foremen in which they divided foremen responsibilities as "full responsibilities", "partial or occasional responsibilities", and "no responsibilities", as the training must generally be preceded by a detailed examination of the features both of the job in question and of the people who are likely to undertake it. Identifying the foreman's responsibilities is the first step to recognize the possible training that he/she may need. "Full responsibilities" refer to those responsibilities that are part of foremen's daily basic duties over which have decision making authority. "Partial responsibilities" are part of the foremen's duties, but not consistently, and consultation with a higher level of management is required before making a final decision. "No responsibilities" refers to the idea that foremen very rarely if ever need to perform this duty. Although this study gives a good idea of the duties and responsibilities of foremen, the construction industry has changed considerably in the past 30 years. Today, foremen's responsibilities and duties are more specific according to the company's and the projects needs. The study presents a very well documented list of foremen duties with their respective descriptions, which has been used to clarify the areas of foremen responsibilities according to the needs of today's construction industry.

Since the training of foremen can be specific depending on the area of work, some differences in responsibilities and duties have been identified in the previously mentioned study. Foremen responsibilities and duties also depend on the company's size, for while in small companies the foreman can handle almost every assigned duty, in large company's responsibilities and duties need to be more specific due to the amount of work involved.

As an important area in which to develop a skill development tool, the foremen's areas of responsibilities needed to be clarified. With the help of studies (Warr and Bird, 1967) to identify the foreman's responsibilities and having a clear idea of the changes in the construction industry in the past few decades new categories of responsibilities have been identified, the most current classification used by the Construction Owners Association of Alberta divides these responsibilities into Safety, Leadership and supervision, Administration, QA/QC, Planning and Scheduling, and Employee Relations.

To design proper training for foremen three areas need to be identified clearly; characteristics of the job, duties and responsibilities, and difficulties faced by each particular individual on his or her work. Each one of these three areas can be impacted by factors related to the company, geographic situation, individual and/or project needs for which some studies (Warr and Bird 1967) suggest identifying these areas clearly before designing a training program. The training needs to have clear purpose, and what area is intended to be improved also needs to be clear. Some foremen need to improve more in certain areas than others who are already successful or doing a good job in that area. There is no need to over train workers, since this has budgetary and time implications for the company, however, some courses are designed to refresh and foster familiarization with new techniques.

Maloney and McFillen (1987) suggest that for better training, a major emphasis on support, work facilitation, and participation may lead to greater worker motivation and improved results. However Warr and Bird (1967) suggest that some aspects such as the size of the company, foreman background, experience, age, and level of education and training have a direct impact on foremen performance, as well as on the training required in order to improve performance and productivity. Although this is a detailed classification of factors that impact the performance of the foremen, the results are open to doubt since the study does not focus on only one aspect, rather it covers various issues that impact foremen training, and gives a general idea, but does not present an exhaustive solution to any of them.

## 2.4 Characteristics of Good Foremen

How good workers perceive their job can be quite different than how other workers perceive their job. The construction industry in particular has to pay special attention to how their foremen perform their respective jobs differently in order to create training programs for each special need.

Lemma et al. (1986) identified 16 factors to analyze a good foreman: Planning of work; assignment of tasks to crew members; ordering and delivery of materials, tools, and equipment; layout of work; communication with craftsmen; showing appreciation to crew; knowledge of craft; innovation; attitude towards safety; daily time analysis; personal background; factors having the most positive effect of crew productivity; factors having the most adverse effect on crew productivity; factors having a positive impact on foremen productivity; areas of responsibility in construction; and factors of job satisfaction for foremen. Even though these 16 factors covered most of the areas that impact the foreman's job, each one of these factors needs to be analyzed individually. However, some foremen work in particular circumstances that the study did not cover or reference. Nonetheless, there is classification of foremen by trade, but this does not cover some conditions that some foremen need to deal with on a daily basis.

In their work Lemma et al. (1986) identify which characteristics differentiate productive from less productive industrial construction foreman, and how the results of that identification can be useful in incorporating them in foremen training programs, or in creating new training programs. After gathering the data, based on how the foremen perform and perceive their job, the highly productive foremen were identified, and their data were separated and analyzed independently from the others. Once the highly productive foremen data were collected and analyzed, the identification of the characteristics of good foremen was created.

The relations between these 16 factors can help us to identify the characteristics of good foremen from less productive foremen. As foremen impact directly upon the crew members and upon production, including the quality of the final product, a particular interest in being able to create training programs to help foremen to improve in their performance is raised. Once these characteristics are identified, a measure of performance can be done using the selected methodology.

The characteristics of main importance in a good foreman identified in Lemna et al. (1986) are the planning of work, ordering and delivering of material, tools, equipment, and scaffold, and communication with craftsmen. In regards to the **Planning of work,** it is well recognized that good foremen plan their work; however, this planning takes place in their mind rather than on paper. The question to answer is whether planning in ones mind is better than planning on paper. High performers seem to plan very well in their minds as they know what their crew members are doing today, and what they are going to do tomorrow. In the area of **Ordering and Delivering of Materials, Tools, Equipment,**

**and Scaffold,** a direct relationship between good and poor performers has not been found; it is well known that higher quality workers tend to order what they need ahead of time in order to prevent delays. **Communication with Craftsmen** also plays a special role in the performance of crew members and their motivation. Generally highly productive foremen are more honest with their crew members in areas like scheduling and planning. Getting crew members involved in the planning and scheduling tends to help foremen in finding a solution or identify a better way to solve future problems that may arise.

The other characteristics identified by Lemna et al. (1986) (such as assignment of tasks to crew members, layout of work, showing appreciation to the crew, knowledge of craft, innovation, attitude towards safety, daily time analysis, personal background, factors having the most positive effect of crew productivity, factors having the most adverse effect on crew productivity, factors having a positive impact on foremen productivity, areas of responsibility in construction, and factors of job satisfaction for foremen) do not present major differences between highly and less productive foremen. It has to be clear however that these results can change depending on such factors as characteristics of the population, geographic location, among others.

It is clear that as highly productive foremen plan their work either in their head or on paper they are also inclined to do more planning than less productive foreman. In addition they also tend to order their materials and tools with more lead time than any other less productive foreman, as they tend to prefer more lead time than their less productive counterparts.

The benefit of the Lemna et al. (1986) study was to recognize three of the main areas that impact foremen performance; planning of work, the ordering and delivery of materials, tools, equipment, and scaffold; and communication with craftsmen. Two of these areas however, (planning of work and communication with craftsmen) do not present anything new from the studies conducted up to then. It was and is well known that planning and communication have a large impact on the performance and productivity of any organization. The results of the study (Lemma et al. 1986), more than being innovative, confirm two of the areas that need special attention in the methodology proposed in this research, and they are being proposed as part of the six areas to evaluate foremen performance.

Although the classification made by Lemma et al. (1986) covers most of the areas where foremen could perform, it is interesting to note that the findings show that highly productive foremen differ from less productive foremen only in the main areas of planning of work, ordering and delivery of materials, tools, equipment, and scaffold, and communication with craftsmen, which raises doubts about the results, since other areas such as knowledge of craft, and personal background, etc. which appear to be obvious, did not reflect any differences between the highly productive and less productive foremen.

Another form of differentiating the performance of foremen is measuring productivity. Hinze and Kuechenmeister (1981) tried to measure the productivity of foremen and their characteristics; however they encountered some problems in determining how to evaluate productivity as there are quite few methods of doing so. Although this study tried to clarify the characteristics of productive foremen, the results are questionable since the authors are not clear on the measurement of productivity. The authors propose to measure the characteristics of good foremen by asking a diverse variety of questions ranging from experience to communication with the crew members, but the study does not compare the results against productivity or performance data such as safety and rework.

Essentially the methodology used by Hinze and Kuechenmeister (1981) is somewhat similar to the methodology proposed by Fayek and Poveda (2008); however it is improved by presenting a mathematical correlation between the results obtained in the questionnaires, and the performance and/or productivity data. Hinze and Kuechenmeister (1981) limited their research to collecting data on foremen's background and personal characteristics, with some additional questions about where it was felt that the foremen's actions could affect the crew's performance.

The Hinze and Kuechenmeister findings imply that productive foreman are not affected by the general foreman in their jobs, and also that they set more difficult though reasonable goals, while at the same time they have equal expectations for all workers. On the other hand, these observations were made in a large project which may change if the scope of the research were to be modified. In addition, some other interesting findings such as the specific questions asked in their study have supported the development of questionnaires to gather the information needed to correlate productivity and performance data.

As a result of the methodology implemented, Hinze and Kuechenmeister (1981) suggest that the effectiveness of a foreman increases with time; foremen with more supervisory experience generally are those who have higher standards of productivity. Though this is a good point, it is also refutable; a foreman with some level of education could have high productivity and less experience. How well the foreman know their crew members and how much time they spend with them communicating are two other factors that can increase productivity. As it is well known that good communication skills are basic in any interaction between workers and their boss, foremen and crew members are not different in this area, and thus productivity can be expected to increase if the communication lines are clear and effective.

Hinze and Kuechenmeister's (1981) results differ from other studies in that they concluded that the success of productive foremen is dependant on their ability to communicate. However, success is still affected by several other factors such as experience, planning, and goal setting. Other authors suggest that success is determined at the planning stage (either planning in their head, or on paper), and influenced by factors such as communication, and the ordering of materials and tools, etc.

## 2.5 Developing Scales to Measure Performance

Generally scales are required to measure the performance of any worker or individual as they offer some level of confidence in evaluating the progress or level of training somebody may require to perform in a proper or effective manner. Two scales that have been developed specifically for the first line foremen are the Behavioral Observation Scales (BOS) developed by Latham and Wexley, (1977) which is similar to the Behavioral Expectation Scales (BES) developed by Smith and Kendall (1963). These two scales however differ on how measurement is applied, and how the group of individuals is observed and rated. Behavioral Expectation Scales (BES) are also known as Behavioral Anchored Rating Scales (BARS). As some authors refer to them as BARS while others prefer BES, the use of the term is irrelevant as both refer to the same scale.

Both measurement techniques (BOS, BES/BARS) are performance appraisals for evaluating the performance of an employee as part of his/her appraisal process. Unlike the BES/BARS technique, the BOS technique includes a process to identify the key task for a job, and evaluate employees according to the frequency they exhibit the needed behavior for achieving an excellent performance. Once the measures of behaviors are tallied they are weighted to reflect the relative significance of the measurement for the job. The values obtained in the observations are added up to obtain an overall job performance score. The procedure in the BES/BARS technique (Smith and Kendall, 1963) can be broken down to four simple steps: identify jobs' key performance tasks, identify the range of behaviors exhibited when the employee is performing each task, locate these behaviors on a scale within a range of ineffective to excellent performance, and finally, assess the worker against these scales for each of the tasks. As every organization tries to maintain or improve their effectiveness, the measurement of performance provides organizations with a useful tool and gives them a level of confidence to evaluate, train, and help to improve the performance of their work force.

Latham et al. (1979) proposed in their research that BOS can be used for first line foremen, however, as the authors recognize, the results are specific to the company that sponsored the research. They also suggest that the procedures used to develop the criteria can be transferred to any other organization, but they do not mention how this can be done, nor do they recommend a technique to do so. In addition the authors recommend using a five-point scale, going from "1 - Almost never" as the lowest value to "5 - Almost always" as the highest value. A detailed scale is not given however, which leaves in the limbo the meaning of the other numbers used in the scale (2, 3, and 4). This scale is used in part of the study but it is not clear what other scales if any are used in other areas of the research.

Al-Hindawe (1996) discusses some required considerations when constructing a semantic differential scale. He agrees with Osgood et al. (1957) that seven-point scales allow for a finer grade of judgment than a five-point scale. Of course, a nine-point scale can also be a finer indicator than a five or seven-point scale, but it can be difficult and tedious to grade evaluations effectively. For our research objective, which is to measure performance throughout time, the seven-point scale was considered the most convenient. Nine-point scales have been rarely used for attitude studies, (Giles et al. 1975) as well the five-point scale has been criticized for giving imprecise results as an indicator of performance (Strongman and Woosley 1967, Bayar 1990). Having as main objective the evaluation of performance throughout the time, the five-point scales' lack of preciseness plays a detrimental role and though it gives a good assessment of the immediate performance, it can be an inadequate tool when used for comparative purposes with future performance appraisals as major improvements need to occur to see the difference reflected on the performance measurement scales.

The methodology used by the authors (Latham et al. 1979) is useful in collecting data from three different groups; superintendents, foremen and hourly employees. In order to develop the Behavioral Observation Scales (BOS), the groups were asked to describe incidents related to foremen, with the results categorized depending on the criteria of analysis. In the present research the tactic used is to gather information from three groups, in this case crew members, foremen, and supervisors (General foreman, superintendents, safety authority, QA/QC manager, etc).

Although the method of interviewing samples from three different groups (foremen, hourly employees and superintendents) gives a relatively comprehensive description of foreman performance, the use of a five-point scale can not be recommended in cases where the performance is intended to be measured throughout the time. A five-point scale gives a good interpretation of results in the specific time the measure occurred, but a seven-point scale is recommended if future comparisons are to be made with previous results. Due to the research results on the use of five-point scales presented by Latham et al. (1979) the present research work proposes to use the seven-point scale. Other benefits of the seven points scale are discussed by Al-Hindawe (1996).

However, there are some advantages to using Behavioral Observation Scales (BOS) as Latham et al (1979) concluded in their study.

1. The BOS is developed with data supplied by the workers to assess others workers.

2. The content is compelling and useful, the successful or unsuccessful behaviors are included in the appraisal, and all the data is used throughout the evaluation.
3. The BOS can be used alone, or used to support an existing job description; and it can be developed to explain what behaviors are needed for an employee in a certain job.
4. The feedback can be used to facilitate improved performance with the use of BOS, and to enhance the relationship between the workers and their supervisor, as well, weaknesses and strengths are easily discussed and understood.
5. The BOS satisfy EEOC (Equal Employment Opportunities Commission) Guidelines in terms of validity and reliability.

It needs to be said that Latham et al (1979) did not make any empirical comparison between Behavioral Observation Scales and Behavioral Expectation Scales in their research. Nonetheless, Atkin and Conlon (1978) summarized some points detailing advantages of BOS, and suggest the use of BOS in order to avoid some problems associated with BES.

1. Explicit endorsement of an incident above the neutral point of BES implies endorsement of all other incidents between the incident in question and the neutral point.
2. The criterion of 'critical" is minimized in the generation of the behavioral items for BOS. BOS focuses on creating a list of behaviors, rating the participants according with the number of times the behavior is exhibited, and analyzes them to determine what behaviors should be included in the final rating.
3. Related to the above criticism of BES is the point that standard or non-critical behavior may not be processed and stored in the same way as non-standard behavior. However, BOS is useful to rank employees since the manager and employee can use it as check list to perform the assessment as they know exactly what they are looking for, thus the performance and future results can be improved.

4. In regards to the idea of using different judges to develop the scales, some authors suggest that a particular supervisor may believe that a particular behavior is more important than others. Some supervisors may also tend to define as acceptable some behaviors that other supervisors would not tolerate, but all of them would have a set of neutral behaviors. To avoid this problem the BOS requires indication of the frequency of the behaviors observed, which are ranked and listed on the scale used.

Miner (1988) developed and applied a new technique called the Rated Ranking Technique for performance appraisal. The rated raking is described in which alternation rankings are followed by a rating of the individuals ranked within the limits imposed by the initial rank orders. While other authors (Barrett 1966, Carroll and Schneier 1982, Bernardin and Beatty 1984, and others) dismiss the topic or their attention to the issue has dramatically decreased, Miner (1988) presents interesting results when the Rated Ranking technique is utilized in an ongoing performance appraisal system; however, the Rated Ranking Technique was not tested. Though, if an adequate testing technique were to have been completed, the benefits in ongoing performances could perhaps have been demonstrated.

The Rated Ranking technique developed by Miner (1988) was created as a necessary tool in order to revalidate a number of tests already in place. In this study Miner suggests that any employee faces a number of demands in their jobs for reasons such as promotion or new requirements in their existing positions, and based on these demands various factors known as performance factors must be implemented. Even though the author proposes these 5 factors other factors may have been neglected. In addition applying these factors to every employee can be unnecessary since not all employees execute every task, which means that while some jobs can be more mathematical and less judgmental, this does not mean the individual does not have outstanding judgmental skills.

Essentially the Rated Ranking Technique consists of ranking the individuals according to a description of the task, and then rating them according to their performance on each of the various aspects of the described task. Although the technique indicates how well one worker did in comparison to another, it does not offer specific information for improving performance. Miner's (1988) study identified five aspects of performance that can relate to the job description or to the tasks performed by foremen, and these have been utilized to develop related questions for the present research.

In the present research the evaluation of ongoing performance is one of the main goals, however, the performance needs to be evaluated using data collected on a specific date, and then compared with another set of data from a different date. The Rated Ranked Technique used by Miner (1988) gives an idea of how to rank and rate the participants, but it does not link the results to evaluate performance in ongoing process. Rather it supports the correlation of performance with demographics as presented by the author, which gives an idea of how to avoid biases that may be encountered. There are a number of ways to obtain information when a performance evaluation is being conducted. One method is to send out the performance evaluation form and wait for the results return. Another method is to complete the performance evaluation face to face, for example, between the foreman and the evaluator. Some authors (Miner 1988) consider that this technique is more consistent from the scientific approach point of view, however, the pressure factor on the employee being evaluated is increased. Not only this technique is quite expensive but also the evaluators may also feel obligated and/or forced to generate the results that the appraiser is expecting.

A weakness of the Rated Ranking Technique is that bias in the evaluation may be presented, for example, some performance measurements can be linked with factors such as age, educational level, job skill level, and company seniority. To illustrate, mathematical task performance can be strongly affected by educational level. Another significant bias found in the study was that performance is associated with racial background in a negative way. Miner (1988) presents how these biases affect the results, but omits the fact that biases can be an important missing link between optimum and poor performance. The ranking approach is heavily criticized by researchers for a number of reasons such as:

1. The distances between the points used in the scale are not clear and accessible.
2. The levels of performance can not readily be identified.

3. The fact that individuals are compared may result in conflicts when the results are presented.
4. The performance is presented as a group, and is not presented in the specific areas of the job description.
5. The technique is commonly dismissed because the definition of performance is not incorporated into the appraisal.
6. The comparison of performance between groups is difficult if a substantial performance variance is not presented.

### 2.5.1 Job Classification for Performance Evaluation Purposes

Measuring performance, but also finding a proper methodology to classify the job is a challenge for researchers as organizations not only must evaluate employees performing different jobs, but these employees also have different levels of experience, proficiency, or responsibility in executing their jobs. Cornelius et al. (1979) provided a methodological approach to classify jobs for the purposes of performance evaluation. While this study provided successful results, the job analysis model used in the study is questionable, and its application to other group of individuals other than those used in this particular research. For job analysis there are several available models, for example, the task-oriented job element approach (Christal, 1974 and Morsh, 1964), the worker-oriented job element approach (McCormick et al. 1972), the abilities-oriented approach .(Fleishman, 1972 and 1975), and other less popular approaches such as, human motivation dimensions (Hackman and Oldham, 1975), critical behaviors (Flanagan, 1954), and physiological data and various industrial engineering approaches (Salvendy and Seymour, 1973).

Although Cornelius et al. (1979) used the worker-oriented approach to develop their study, as was previously mentioned; the use of this approach is open to discussion due to its limitations. However two or three of these techniques can be combined to get an optimum result which can be applied to any industry and/or organization.

The **job-oriented approach** focuses on, and pays special attention to the specific tasks involved in performing a job, and the outcome of that job on level of productivity.

The **worker-oriented** approach focuses on employee behaviors on the job, and the specific skills, abilities, and personal qualities needed to perform the job effectively. As was mentioned previously, the results of Cornelius et al. (1979) are questionable since comprehensive job analyses involve a combination of job-oriented and worker-oriented data. Applying only the worker-oriented approach while leaving the job-oriented approach out of the picture may mean that the researcher is neglecting some specific tasks performed by the workers in their specific job, and as such the evaluation is not as comprehensive is possible. While the worker-oriented approach pays attention to the specific skills, abilities, and qualities to perform the job, it also includes the level of productivity or the outcome of that job, which means that the product of the application of those abilities, skills and qualities are not evaluated in its entire context.

A question arises when it comes to foremen performance and job classification. Should foremen be classified, or can they be evaluated using the same methodology as supervisors or crew members, if only because their jobs are related? The literature on performance appraisal gives different approaches on this topic. One important approach suggests to develop as many different performance appraisal forms as the organization needs to evaluate each one of the many tasks performed by the employee, while another important approach proposes looking at generalities or commonalities and developing a single evaluation form. The obvious disadvantage of this second approach is that there are a wide variety of tasks, demands, and unique skill sets necessary to perform each job, and as such one evaluation form likely would not be adequate.

Cornelius et al. (1979) came to the conclusion that there is no need for developing unique performance evaluation forms for each job and/or each task. Nevertheless individuals and their specific roles within their specific organizations need to be considered. Obviously not every organization operates in the same way, a unionized company responds differently than any other construction organization, thus when a new methodology is implemented these differences need to be accounted for.

In order to implement the methodology in the present research, a combination of the **job-oriented approach** and the **worker-oriented approach** was discussed and incorporated at some level. As the job-oriented approach considers the specific tasks involved in performing a job, and asks what is the measurable outcome of that job on the level of productivity, it was beneficial to study in detail what tasks the foremen perform on a daily basis in order to develop the set of questionnaires and manuals proposed in our methodology. Also, as was discussed previously, the worker-oriented approach focuses on employees' behavior on the job, and on the specific skills they need to perform the job, as well on their abilities and personal qualities. Using solely either the worker-oriented approach or job-orientated approach could lead to questionable results for the reasons discussed previously, as well, separating the behavior of the workers from the specific tasks that they perform only evaluates the performance of the foremen half way, leaving the correlation between the performance and productivity unanswered.

Although Cornelius et al. (1979) used only the worker-oriented approach and the results could be questioned by others whom use different approaches, it does give a better idea of why and how the job-oriented approach and the worker-oriented approach should be used together in order to generate a more comprehensive performance evaluation of foremen. The combination of these two techniques not only gives more comprehensive and accurate results, but it can also be applied to any kind of job, as both techniques cover all aspects of performance that should be taken into consideration when evaluating performance.

## 2.6 Foremen's Influence on Performance

There are many people and a large variety of specific workflows involved in every organization no matter what industry the organization is in, and the construction industry in particular is complex, large, and unique due to the wide variety of specific characteristics of the many construction projects worldwide. Is it in interest of management to know how, and how much their workers impact the performance of the organization? In the case of the construction industry, foremen as a group receive particular interest since they are considered to play a critical role for the companies' performance due to their first line of supervisory role and their impact on the performance and productivity of the work force.

In an attempt to obtain a better perspective on foremen behavior and how they impact performance, Maloney and McFillen (1987) identified five areas of foremen behavior, basing these areas on the individuals' influence on performance which are then evaluated and potentially improved. The authors categorize these areas as follows:

1. The degree of participation allowed by the foreman in decision-making.
2. The level of support provided by the foreman.
3. The degree of the foreman's achievement orientation.
4. The degree of foreman bias.
5. The level of work facilitation provided by the foreman.

As these five areas are related directly with worker motivation, performance, and satisfaction, other important areas of consideration such as productivity are missing in this study. A brief description of these five factors can be presented as:

- **Participation** is related with to what extent the foremen permits the workers to get involved with the decision making process. Generally these decisions involve the work, and the work environment.
- **Support**: The foremen can be considered as therapist and tutor for his/her crew members. The foreman is a guide for the work force to overcome their problems, and help them to accomplish their goals.
- **Achievement orientation** is linked with the stimulation of enthusiasm by the foremen, and to the emphasis on achieving outstanding performance.
- **Bias** is associated with the foreman's possible positive and or negative discrimination of any of the workers.
- **Work facilitation** involves the foremen directly with his/her ability in getting the resources necessary to perform, plan, schedule, define tasks, and coordinate and control the workforce.

As motivation plays an important role on employee satisfaction, there is a direct link between foremen motivation with workers performance. Some authors (Maloney and McFillen 1983, Maloney and McFillen 1985, Maloney and McFillen 1986) have proven the importance of foreman influence on workers' motivation, performance, and satisfaction. Foremen influence and worker motivation is based on the idea that foremen must match each workers' abilities with his or her duties as doing so is the best way to satisfy worker expectations and the company's needs, and thus the expected results can be realized. However, communication skills play a significant role for the foremen to accomplish this task. The communication line must be clear and specific, as incorrectly assigning workers their tasks can affect the motivation, performance, and satisfaction for both parties.

In the Maloney and McFillen (1987) study, the critical point of how workers perceive their foremen emerges. In every crew led by a foreman some relationships do not work as well as the management hopes. If a study is based only on the workers' perception of their foremen, some adjustments need to be made to the original data collected, otherwise possibly existing biases may have negative effects on the results.

Demographic factors can affect the foreman's and the workforce's performance. Maloney and McFillen (1987) present their study based on five factors (participation, support, achievement orientation, bias, and work facilitation) affected by demographic variables. In the case of participation and support, only union membership and age presented a significant difference in foremen and workforce performance. For achievement orientation, the only demographic variable with a significant effect on performance was union membership. Bias presented significant performance differences in regards to union membership and age. While in regards to work facilitation, the only significant change was presented in union membership. Although this is a valid approach, other demographic variables such as ethnic background, education level etc., have not been included. Additionally, the authors do not present valid explanations for their findings, there are unexplained differences in each of the factors when combined with the membership and age variables, but they justify their results by saying (Maloney and McFillen, 1987):

> "Neither the study nor researcher intuition provides a clear explanation of the findings. No obvious explanation exists or the differences. This explanation is pure speculation and must await further evidence to establish its legitimacy."

Justifications such as this put the results of the study in doubt, either because an incorrect method was used, or the analysis was not deep enough to clarify the findings.

However five elements of foreman behavior can be identified, namely, participation, bias, work facilitation, achievement orientation and support which can be linked with worker motivation, performance, and satisfaction. The missing element is to what extent foremen influence the performance within this relationship. Nevertheless, there is a clear relationship between these five elements and performance results, to the point that it is believed that better supervision produces better results.

Since foremen have a strong impact on work force performance, satisfaction, motivation, among other factors there is every reason to pay special attention to foreman training and selection. Additionally, foremen responsibilities change from job to job and from company to company, giving the job a multitude of variations, thus not only the selection and training of the foremen needs to be designed according to the specific requirements of the job, but so to does the follow up of their performance as well.

In view of the fact that the performance of the work force is directly affected by their foremen, major efforts to eliminate or reduce bias created for different reasons, and also to improve the work environment to help the foremen perform to the best of their abilities ought to be taken. Not only does the work environment need to be improved, but so to does the planning, scheduling, goal setting, and communication, which is why training has to be designed which considers the unique characteristics of each job and each foreman's skill set.

As one of the main objectives of the present study, the evaluation of performance has to be designed with a purpose, either to evaluate the workers, or design a training program to improve the performance of the work force. Developing better workers is the intent of every organization that believes in their employees Thus the results obtained by Maloney and McFillen (1987) on how the foremen can affect not only their own performance, but also that of the crew members and in turn on the productivity of the organization, combined with such methodologies as the **job- oriented approach** and the **worker-oriented approach,** can give results which are expected to be more accurate.

The size of the project can also be considered as a factor that influences productivity and performance. Today's construction industry is facing ever larger projects with increasing size and complexity with new problems developing as existing problems intensify. Morse and Borcherding (1980) studied the impact of work force motivation and job conditions on productivity, quality, turnover, and absenteeism concentrating on foremen data. The authors collected a considerable amount of data to support their research. However using results from five different projects, each of them with unique characteristics, can be a risky task due to the distinctiveness and uniqueness of each project. Mixing data from a project located in the USA with a project in Canada, even from the same company, also has some special considerations that need to be addressed when it comes to analyzing the data and presenting the results.

As an important aspect in our research, the size of the project has to be considered when it comes to proposing a methodology that is expected tó be implemented in every project without differentiate how large the project and/or the organization is. Morse and Borcherding (1980) give an idea of how to approach the foremen without distinguishing between the sizes of the projects they are working on. Practically, morale and motivational aspects play a key role, and they are related to worker performance. Although most organizations know that these two factors are important in their workers' performance, there is also the recognition that it is difficult to measure them. However, in the present research methodology these two factors have been taken into consideration when designing the questionnaires to get the best response from the individuals involved in the performance evaluation process.

Thus some aspects of how the foreman handles and interacts with his or her crew members concern management as employee motivation and morale have an important role in the employee's final performance, the foreman is hired to perform, and to achieve results measured in productivity.

Some of the major productivity problems described by Morse and Borcherding (1980) are waiting for decisions and rework, which impact directly on performance and productivity and lead to feelings of frustrations between foremen and management which often pass on to the crew members. Though these two problems described are valid, there are other examples that can result in the direct the foremen and/or their crew members to perform below their expected abilities, and resulting in their feeling frustrated with their work and/or their company. (See Section 1.1)

Morale problems also relate to productivity problems (Morse and Borcherding, 1980), for example, the issue of waiting for decisions, can result in frustration for the foremen and their crew members. They often feel demoralized if they have to stop what they are doing because of the need to wait for decisions, or the arrival of tools or materials. Most workers including foremen would rather feel productive than attempt to look busy when they are waiting. The factor of employee discouragement due to the need to wait for implementation of decisions or the feeling that they should be further ahead with their jobs needs to be taken into consideration when it comes to worker motivation. The other aspect related to morale is rework, certainly any employee gets disappointed, frustrated or discouraged when things are not done properly the first time, and this has not only productivity, time, and budget consequences, but it also impacts on the morale and motivation of the workers.

### 2.6.1 Foreman's Influence on Apprentice and Journeyman Performance

The foremen also have considerable influence over manpower and time (Uwakweh 2005). Not only do the foremen have to plan, control and coordinate their crew members but they also have to motivate them to perform effectively. Giving the proper training to qualify and motivate apprentices guarantees the best quality product in the construction industry.

How the journeymen and apprentices perform is directly related to their foremen since the foreman is the first link between the apprentice and management. Uwakweh (2005) presents seven factors to evaluate this relationship: Performance Improvement, Work Facilitation, Achievement Orientation, Support, Work Participation, Bias, and Recognition. Although this study presents some interesting areas of research, other factors that relate to foremen influence such as motivation, safety, leadership, employee relations, quality control and assurance have not been included in the study. Basically Uwakweh (2005) correlated seven factors that affect the journeyman and apprentices' performance and the subsequence training programs. The factors identified present variables within themselves; although this classification of factors considered by the author seems to be coherent, some of the variables can be questioned as to whether they accurately represent how the foreman affects the performance of the apprentices and journeymen. The results are presented as follows, and though there are many other factors that are not covered in the study, this study nevertheless offers a good basis of criteria to develop further studies in this area.

The seven factors mentioned above are:

- **Performance Improvement** measures how the foremen help the apprentice to perform the job.
- **Work Facilitation** is related to the actions and activities that the apprentice demonstrates to prove they know their job and have the abilities to perform their tasks.
- **Achievement Orientation** is the factor linked to the behaviors that foremen display to their crew members which encourage them to work at a high level of performance and to accomplish their goals.
- **Support** can be interpreted as the psychological part of the foreman's job. This relates to how the foremen care for the welfare and psychological well being of their crew members, and their help in dealing with the crew members' personal problems
- **Work Participation** gives the opportunity to apprentices to be involved in the decision making process and relates to how much their foremen support them in this part of their job by providing them with the opportunity.
- **Bias** plays an important role in the apprentice's satisfaction since this factor relates to foremen discrimination between workers for performance reasons.
- **Recognition** is associated with recognizing apprentices for their good performance and also garners their respect.

Analyzing the foremen factors by trade, the areas that need improvement are work facilitation, work participation, support and bias. Training programs can be designed to help foremen advance in these areas, dependant of course on the geographic area and the particular characteristics of the population. Generally apprentices tend to learn faster and better if their foremen are involved in the job that needs to be done. If apprentices get the chance to clarify their ideas and understand why things are done in a certain way the quality of performance also tends to be higher. As well, since the majority of apprentices plan to become journeymen which requires excellent training and opportunities, effective foremen and supervisors provide a well trained individual the opportunity to accomplish their goals. If foremen gain respect from their crew members, plan out work in advance effectively, give clear instructions, and facilitate the performance of their apprentices, the quality of the work in the construction industry can be at the highest levels of professionalism, and outstanding professionalism from all crew members, including the supervisors and foremen, can be expected.

Most of the variables presented by Uwakweh (2005) have been considered to develop a series of questionnaires that is part of the methodology presented in this research, however the classification of the factors have been modified according to six areas that cover the responsibilities of today's foremen; safety, planning and scheduling, leadership and supervision, employee relations, QA/QC, and administration. In order to evaluate the foreman's performance and design the subsequent training, some of the factors involved in Uwakweh's (2005) study support the formation of a number of questions to be included in performance evaluations, but most importantly it contains evidence that the foremen impact directly on their apprentice and journeymen performance.

The impact of effective supervision on workers performance was modeled by Gannoruwa and Ruwanpura (2008) identifying and assessing the relationship between the crew and supervisory stile. The study identify the motivational level of construction workers due to their supervision, also quantify their technical skills and motivational levels for the development and analysis of a new Workers' Readiness Grid (WRG), anchored by motivation based on supervision, workers' skill level and the most dominant supervisory styles can result in better supervision. The WGR identified basically four supervisory stiles; technical guiding, delegation, mentoring and motivation, and correlated them with workers performance. Although the study demonstrated that effective supervision affect the performance of workforce, it also ignored to correlated external factors that may impact that performance, and if so, to what extent.

## 2.7 Application of Fuzzy Logic in Construction

The use of the Fuzzy Logic is increasing rapidly since its creation by Zahed (1965), and was developed specifically to deal with uncertainties that are not statistical in nature, though it must be said that the number of areas where Fuzzy Logic Theory can be used or applied is unlimited. The most popular use of the Fuzzy Logic Theory is to represent the uncertainties of real-life situations in the measurement of productivity and the prediction of performance. In the construction industry Fuzzy Logic Theory became popular in the early 1980s, and its use has increased rapidly since then (Knight, 2001). Fuzzy Logic also provides a clear representation of the state of activities and events, and it introduces itself well into systems which facilitate easy modeling with insufficient data. In Fuzzy Logic a statement is true to various degrees, ranging from true to false, or from high to low depending on the linguistic representation used. Elements belong to a fuzzy set to different degrees, called grades or membership. The use of grades of membership in fuzzy set facilitates the easy construction of expert systems. Fuzzy logic is a form of multi-valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. Just as in fuzzy set theory the set membership values can range (inclusively) between 0 and 1, in fuzzy logic the degree of truth of a statement can range between 0 and 1 and is not constrained to the two truth values {true, false} as in classic predicate logic. The fuzzy logic was developed to deal with uncertainties resulting from imprecision and vagueness.

Fuzzy Logic can be applied to a set of data in order to take into account the quantitative and qualitative factors that affect performance. The Fuzzy Logic Theory has also been used in risk management during construction (Ross et al., 1994; Thiel et al., 1985; Dabah et al., 1998; Lee et al., 1995). Areas such as safety have also been explored using this method by Beer et al. (1998). In the area of environmental engineering the fuzzy logic theory has been used to estimate unmeasured variables such as the influent substrate and recyclable biomass concentrations in the operation and control of a high purity oxygen-activated sludge process (Yin et al., 1999). Geotechnical engineering has been also explored using Fuzzy Set Theory; for example, some scholars have applied this approach to CPT soil classification (Zhang et al., 1999).

Additionally, Fuzzy Logic Theory has been used in almost all areas of civil engineering. For example, Russell et al. (1994) utilized Fuzzy Logic Theory for developing an automated corrective action selection system. Fayek (1998) applied Fuzzy Set Theory to the markup size selection, and Chao and Skibniewski (1998) used a Fuzzy Logic approach to evaluate alternative construction technologies. Fayek and Sun (2001) developed a complex model fuzzy expert system which models design project performance based on the techniques of Fuzzy Logic Theory, and cost estimating relationships were used by Mason and Kahn (1997), using the fuzzy set theory to describe the process of estimating construction excavation costs, in a situation where data is insufficient. A Fuzzy Logic technique can be also used to represent systems in which there is insufficient data (Mason and Kahn, 1997).

The Fuzzy Logic technique is an alternative to represent complex situations is simple models in a short period of time with the use of an uncomplicated computer environment. Because of the characteristics of construction industry projects, the collection of data is a tedious and arduous task, for which a Fuzzy Logic approach is one of the most suitable. Fuzzy Logic is a generalization of set theory. It was developed specially for dealing with uncertainties and vagueness that are not statistical in nature. Among its other benefits, it provides an excellent form to quantify linguistic terms. In addition, it offers the ability to relate multi-inputs to the output, especially when the reasoning relationship is difficult to express in numeric equations or involves linguistic judgment. Problems that involve natural language, subjective judgments, complex relationships, and limited data are perfectly suitable for analysis using Fuzzy Logic.

In this study, a Fuzzy Logic approach is developed, and it can be used by management to evaluate and to predict performance of construction trade foreman in the construction industry. This approach makes linguistic or qualitative assertions about the relationship between performance and the factors affecting it.

## 2.8 Measuring Performance Evaluation

There are a variety of methods to evaluate performance. Furthermore, a differentiation of the type of performance to be evaluated needs to be identified. Design performance, employee performance, management performance, and machinery performance are some of the forms of performance that can be measured. The present study focuses on employee performance and more specifically "Foreman Performance". Though statistical models exist in the collection of data and for the analyzing of the results using mathematical approaches, the main purpose of this study is to use a innovative technique known as Fuzzy Logic Theory to evaluate and predict performance of employees, in this case foremen.

A number of studies have attempted to link employee performance with the outcome of an operational or productivity goal using the Total Quality Management Principles (Deadrick and Gardner,, 2000). Essentially, performance systems links the goals of organizations and employees to a set of expectations, and then links employee achievements to a series of human resource decisions through a performance measurement process. Deadrick and Gardner use the PDA (Performance Distribution Assessment) method in three different stages: pre-appraisal stage, appraisal stage, and post-appraisal stage. Once the authors identify the advantages of using the PDA method they link this to the TQM (Total Quality Management) goals. The PDA and TQM approaches to performances management diverge somewhat in terms of the assumptions made about the system and human causes of performance. (Deming, 1986) and other TQM advocates claim that a high percentage variation between employees is attributable to system factors, no person factors.

Some authors certainly question the assumption about the relative impact of the system and worker factors on performance (Cardy and Dobbins, 1994). Although research has demonstrated the effects of the system and the worker factors on performance, there is a disagreement regarding the findings between Deming (1986) and others such as Dean and Konstans (1986), and Steel and Mento (1986) who argue that the system does not have an appreciable effect on employee performance.

Other, less comprehensive studies have focused strictly on the methodology to improve the performance of workers (e.g., supervisors). Rogge et al. (1996) presented a report to the Construction Industry Institute at the University of Texas at Austin in which they developed a process of continuing supervisory education to improve performance of supervisors. In their research, the authors identify and address the educational needs of supervisors in the construction industry throughout a full career. The owners, designers, and construction supervisors were also studied. The study however, only focuses on supervisory skills and does not include the technical skills that are important when it comes to improving the overall performance of supervisors. The authors also propose a handful of methods for improving supervisory performance such as rotational job assignments, coaching, mentoring and other non-classroom methods, as well as other more traditional methods of education and training.

In an attempt to develop a methodology that involves all of the various aspects of a foreman's daily work and link them to an overall performance evaluation, Fayek et al. (2008) developed a methodology for the Construction Owners Association of Alberta in which the authors take into consideration traditional methods (mathematical/statistical approach), and contemporary methods (360-degree review) to evaluate the performance of workers (foremen). In order to implement such methodology, the authors compiled a series of previous studies that involve all the aspects in the foremen environment such as foremen responsibility areas, knowledge, technical skills, attitude, training, education level, and experience. The results of this study have been used to develop and implement the Construction Trades Foreman Skills Development Tool in the Alberta construction industry, and is also the basis of the present research thesis.

## 2.9 Performance Evaluation and Fuzzy Logic

In a more general approach some research has been done to model and predict performance of qualified professionals such as architects and engineers using regression models (Ling, 2002). The author based the prediction of performance on a series of characteristics that the candidates must have in order to perform effectively. Georgy et al. (2005) used the Neurofuzzy approach to predict the performance of engineers and design professionals. To evaluate the impact of quality of engineers in construction projects, Georgy and Chang (2005) used the Fuzzy Neural Network Approach. Since the performance will always be linked to productivity; Fayek and Oduba (2005) used the Fuzzy Expert systems to predict industrial construction labor productivity. Sonmez and Rowings used the Neural Network approach (1998) in a similar study to measure construction labor productivity. Portas and Abourizk (1997) also used the Neural Network approach to estimate construction productivity. The Neurofuzzy system combine the advantages of fuzzy systems, which deal with explicit knowledge which can be explained and understood, and neural networks which deal with implicit knowledge which can be acquired by learning. Neural network learning provides a good way to adjust the expert's knowledge and automatically generate additional fuzzy rules and membership functions, to meet certain specifications and reduce design time and cost. On the other hand, fuzzy logic enhances the generalization capability of a neural network system by providing more reliable output when extrapolation is needed beyond the limits of the training data. On the other hand, the fuzzy neural network is a hybrid intelligent system of soft computing technique, the fuzzy neural network (FNN) is an efficient tool to deal with nonlinearly complicated systems, in which there are linguistic information and data information, simultaneously.

While the Fuzzy Logic Theory has certainly been used extensively in the construction industry among other areas, it is legitimate to mention that Fuzzy Logic has not been used to an expected extent in evaluating the performance of employees outside of the management level (e.g., foreman, general foreman, and supervisors). Fuzzy Logic Theory is perfectly suitable to evaluate and predict the performance of all employees not only due to the general characteristics of the theory and the complex factors involved in the process of such an evaluation but also because the linguistic nature of assessments and the relationship between the factors involved in performance evaluation and the output variables. The advantages and benefits of using fuzzy logic to evaluate and predict the foreman's performance will be discussed in further sections of this thesis.

Ammar and Wright (1995) presented their conclusions of using a Fuzzy Logic approach to performance evaluation on customer satisfaction. Although this would be an acceptable approach for customer services companies where the customers have direct interaction with the specific employees to be evaluated in the construction industry the interaction between the foremen and the direct clients of the companies is almost certainly zero. Furthermore, a foreman's performance evaluation based on customer satisfaction would be an unrealistic approach, and the results would be highly debatable.

In contrast with the Ammar and Wright (1995) research, the present study takes into consideration the assessment of three different groups (supervisors and peers, crew members, and foremen) to evaluate the performance of foremen (first line supervisors). The main purpose is to obtain an assessment from the personnel who interact directly with the foremen; the complete methodology will be discussed in the following chapters of this thesis.

## 2.10 Summary

Several models have been developed to evaluate performance. However, very few of them focus on performance evaluation of labor. In the present chapter, the foreman characteristics and impact in productivity have been reviewed extensively. To design a model to predict and evaluate the foreman's skill level assessment, it is necessary to take into consideration not only the effect of the foremen on productivity but also a series of factors that affect the performance of the individuals in the work environment.

Because of lack of research and application of computer techniques to evaluate and predict the performance the present study will use Fuzzy Logic. The present research applies Fuzzy Logic to the evaluation and prediction of performance (Foreman's skills level assessment). The Fuzzy Logic Theory has been chosen as it suits the nature of the problem to be solved due to the problem's qualitative, subjective, and imprecise characteristics. This thesis has also been inspired by the desire to apply fuzzy logic theory to a new application area of research in the construction industry.

# CHAPTER 3 FACTORS INVOLVED IN FOREMAN'S PERFORMANCE EVALUATION

## 3.1 Identifying Factors Involved in Foreman's Performance Evaluation

### 3.3.1 General

Performance is such a complex process that no single factor can be used to predict or evaluate it. A series of factors that affect the performance must be considered before a certain methodology can be applied to evaluate or predict it. First, performance involves assessments from a number of groups, including managers, supervisors, foreman, and crew members. Although this research focused on foreman's performance evaluation, the assessment groups cannot be considered in isolation. One has to look at this problem from a wider perspective to considerer all of the groups involved.

Second, performance evaluation is a dynamic process that not only involved the assessment groups but also a number of areas that must be taken into consideration; responsibilities, knowledge, skills and attitude, and qualifications. To evaluate the foreman's performance one not cannot use one simple factor such as the qualifications (e.g. training, education level, and experience) since these are not the only factors that affect the performance. There are many other factors that affect the foreman's performance before even the qualifications can be considered, once the foreman completes his training a new series of variables must be used to evaluate his performance. On that note, we have to find a systematic and complete set of factors to evaluate the foreman's performance.

Third, the foreman's performance evaluation may vary depending on different situations or project characteristics. Different project locations may impact the behavior of employees and their personal interaction dynamic, different climates, types of owners, company polices, etc, will all have a considerable effect on the foreman's performance. However, these factors can be considered stable for a specific area. Because of the unique characteristics of each construction project these factors will have a great effect on the foreman's performance, even if we compare two projects with similar characteristics the performance will always be affected by the unique factors that surround each particular employee in the project.

Overall, the foreman's performance needs a complete, dynamic, and comprehensive set of criteria for evaluation. A complete literature review was conducted to collect a broad list of factors affecting the foreman's performance evaluation (Fayek and Poveda, 2008). These factors can be classified in six groups according to areas of responsibilities; safety, QA/QC, leadership and supervision, labour relations, planning and scheduling, and administration.

### 3.1.2 Classes of Factors

The Construction Owners Association of Alberta (COAA) developed the construction trades foremen job description that consists of tasks and/or duties that the foremen could perform in their daily basis divided in six areas of responsibility, based on these areas of responsibility the foreman can be evaluated taking into consideration each task in his daily schedule. This classification of factors by areas of responsibilities takes into consideration other areas such as knowledge, skills, attitude, and qualifications. Independently from the areas of responsibility (safety, QA/QC, leadership and supervision, labour relations, planning and scheduling, and administration), the foreman's performance will be affected by factors such as training, education level, experience, knowledge, skills, attitude, company policies, work environment, etc. In each category a number of factors have been identified to create a series of aspects to evaluate the foreman's performance.

The input variables have been divided according to the categories given by the methodology adapted in preliminaries phases of the model. The number of input variables varies depending on the category to be evaluated; in each category the foremen must perform a certain number of tasks which were re-grouped according to similarity among them. Each input variable was determinated by 3 or 4 questions in the self-responded questionnaires that evaluate specific criteria in each category. The number of input variables for each category is as follow:

- Safety: 4 input for each assessment group
- QA/QC: 2 inputs for each assessment group

- Leadership and supervision: 5 inputs for each assessment group
- Employee relations: 3 inputs for each assessment group
- Planning and scheduling: 4 inputs for each assessment group
- Administration: 3 inputs for each assessment group

- Safety factors

  In this area the foreman must facilitate a safe work culture, is accountable for the safety of the crew, and must understand the legal liability of the role. The foreman must ensure that crew members apply the standards for safe working conditions and are fit for work each day. The aspects to evaluate in this area are listed in Table 3-1:

Table 3-1: Safety Factors

| **Input Variable** | **Factors** |
|---|---|
| Technical Knowledge | Understanding of HSE good practices<br>Understanding of HSE procedures<br>Knowledge in Worker's Compensation Board<br>Knowledge in insurance provisions |
| Company Policies | Understanding of the company safety program<br>Knowledge of safe work practices<br>Knowledge of safety policies<br>Knowledge of safety procedures<br>Knowledge of the company drug and alcohol policies |
| Safety Procedures | Understanding of safety and hazard assessments<br>Participation in safety/incidents investigations<br>Effectiveness in incidents and safety reports |
| Safety Development for Crew | Knowledge of technical safety areas<br>Development of safe work plans for crew members<br>Conduction of meetings (e.g., safety tool box meeting)<br>Identification of training for crew members<br>Arrangement of training needed by crew members |

- QA/QC Factors

  In this area the foreman is accountable for ensuring the work done meets standards, and for recommending work processes to improve productivity and product quality. The aspects to evaluate in this area are listed in Table 3-2:

Table 3-2: QA/QC Factors

| Input Variable | Factors |
|---|---|
| Inspection and resolution of QA/QC problems | Understanding of company's QA/QC expectations<br>Ability to resolve technical issues<br>Ability to solve QA/QC related issues |
| QA/QC specifications | Ability to ensure that crew members work according to standards (e.g., blueprints)<br>Ability to ensure that crew members work according to QA/QC company's specifications<br>Understanding of the correct use of tools and equipment<br>Inspection of work and corrective actions taken |

- Leadership and Supervision

  In this area the foreman leads the crew and is accountable for how the crew completes the assigned work, and must understand and consistently apply the employer's policies. The aspects to evaluate in this area are listed in Table 3-3:

Table 3-3: Leadership and Supervision Factors

| Input Variable | Factors |
|---|---|
| Oral and written skills | Oral communication abilities<br>Written communication abilities |
| Knowledge of crew and scope of work | Knowledge of trade's scope of work<br>Ability to read blueprints<br>Ability to apply specifications<br>Capacity of assessing other abilities<br>Ability to match other's abilities with task assignments<br>Knowledge of crew member's responsibilities and duties |
| Responsibility at work and work ethic | Punctuality and presence at work<br>Ability to promote pride and workmanship<br>Responsibility and reliability at work<br>Work ethic<br>Integrity<br>Honesty<br>Capacity of setting an example of behavior<br>Ability to ensure moral and productivity of crew members |
| Decision making abilities | Ability to make decisions on time<br>Capacity of adaptation and flexibility<br>Capacity to anticipate and avoid problems |
| Team work | Ability to work in groups-team player<br>Understanding and promoting team work and harmony within crew members<br>Ability to guide new crew members<br>Coordinating job training and mentoring |

- Employee Relations

  In this area the foreman must champion an inclusive employee relations culture and is accountable for the adherence to employee relations policies and procedures by crew under his/her direction. The aspects to evaluate in this area are listed in Table 3-4:

Table 3-4: Employee Relations Factors

| **Input Variable** | **Factors** |
|---|---|
| Crew issues | Showing respect for crew members and supervisors<br>Ability to include and discuss with crew members work related issues<br>Capacity to coordinate and communicate with others<br>Ability to recognize, address, and resolve issues/problems within crew members<br>Ability to identify training needed |
| Disciplinary action | Ability to document issues/problems with crew members<br>Capacity to investigate and document incidents<br>Ability to apply company's corrective action policy |
| Company policies | Ability to apply project procedures<br>Ability to apply worksite policies and collective agreements<br>Ensuring a respectful work environment<br>Understanding of the company's employee relations policies |

- Planning and Scheduling

  In this area the foreman is accountable for following project plans and schedules and ensuring the crew's daily and weekly activities meet production goals set by the company. The aspects to evaluate in this area are listed in Table 3-5:

Table 3-5: Planning and Scheduling Factors

| **Input Variable** | **Factors** |
|---|---|
| Planning abilities | Understanding of project schedules<br>Appling project schedules effectively<br>Identifying plan/schedule's needs and deficiencies<br>Participating in preparing look-ahead schedules |
| Workface/detailed planning | Ability to translate work requirement to crew members<br>Capacity to plan manpower requirements<br>Ability to plan scaffold requirements<br>Ability to plan ahead<br>Identifying tool and materials needed |
| Communication to crew members/other crews | Ability to communicate schedule and scope of work<br>Team work to overcome challenges<br>Ability to resolve schedule problems or conflicts<br>Ability to report schedule problems or conflicts |
| Meeting weekly targets/productivity | Ability to adjust workface activities<br>Understanding of weekly schedules and production targets<br>Ability to identify and resolve road blocks |

- Administration

  In this area the foreman is accountable for the preparation of reports as required by the employer or supervisor. The aspects to evaluate in this area are listed in Table 3-6:

Table 3-6: Administration Factors

| **Input Variable** | **Factors** |
|---|---|
| Documentation | Ability to keep and update logs or dairies<br>Capacity to maintain accurate time cards<br>Ability to report workface production and work progress<br>Ability to complete quality reports<br>Ability to complete the statistics required |
| Communication skills | Ability to complete reports<br>Capacity to recommend personnel actions<br>Computers skills |
| Logistics | Ability to require supplies on time<br>Ability to obtain permits on time<br>Distributing cheques on time and handle cheques problems effectively |

## 3.2 Identifying Measures for Each Factor Involved in Foreman's Performance Evaluation

Even though a thorough list of factors that are involved in the foreman's performance evaluation, a consistent scale has been used to measure each one of them. Two different scales have been described; linguistic and numerical. The linguistic scale must be according with the criteria to be evaluated, in this case performance. For example, if weather is being evaluated the logic scale to use is: very hot, hot, warm, cold, and very cold, in our case, to measure performance the linguistic scale used was: poor, acceptable, and outstanding, in the case of having three membership functions. Another scaled used in this research was very poor, poor, acceptable, good, and outstanding in case of having five membership functions.

A 7-point BOS (behavioural observation scale) was chosen to evaluate east criteria. The 7-point scale was selected after considering a series of factors: it has a natural midpoint (4) that serves as neutral rating (e.g., neither low nor high). Anything above 4 is considered positive (e.g., high), and anything below 4 is considered negative (e.g., low). The 7-point scale also allows the user to measure the improvement in performance over time. The description of linguistic and numeric scale is shown in Table 3-7.

Table 3-7: Input Factors Involved in the Foreman's Performance Evaluation

| Factor No. | Name of Factor | Linguistic Descriptors | Numerical Scale |
|---|---|---|---|
| Input # 1 | Technical knowledge | Poor, acceptable, outstanding | 1-7 rating |
| Input # 2 | Company policies | Poor, acceptable, outstanding | 1-7 rating |
| Input # 3 | Safety procedures | Poor, acceptable, outstanding | 1-7 rating |
| Input # 4 | Safety development for crew | Poor, acceptable, outstanding | 1-7 rating |
| Input # 5 | Inspection and resolve QA/QC problems | Poor, acceptable, outstanding | 1-7 rating |
| Input # 6 | QA/QC specifications | Poor, acceptable, outstanding | 1-7 rating |
| Input # 7 | Oral and written communications skills | Poor, acceptable, outstanding | 1-7 rating |
| Input # 8 | Knowledge of crew and scope of work | Poor, acceptable, outstanding | 1-7 rating |
| Input # 9 | Responsibility at work and work ethic | Poor, acceptable, outstanding | 1-7 rating |
| Input # 10 | Decision making abilities | Poor, acceptable, outstanding | 1-7 rating |
| Input # 11 | Team work | Poor, acceptable, outstanding | 1-7 rating |
| Input # 12 | Crew issues | Poor, acceptable, outstanding | 1-7 rating |
| Input # 13 | Disciplinary action | Poor, acceptable, outstanding | 1-7 rating |
| Input # 14 | Company policies | Poor, acceptable, outstanding | 1-7 rating |
| Input # 15 | Meeting weekly targets/productivity | Poor, acceptable, outstanding | 1-7 rating |
| Input # 16 | Communication to crew members/others | Poor, acceptable, outstanding | 1-7 rating |
| Input # 17 | Planning abilities | Poor, acceptable, outstanding | 1-7 rating |
| Input # 18 | Workface/detailed planning | Poor, acceptable, outstanding | 1-7 rating |
| Input # 19 | Documentation | Poor, acceptable, outstanding | 1-7 rating |
| Input # 20 | Communication skills | Poor, acceptable, outstanding | 1-7 rating |
| Input # 21 | Logistics | Poor, acceptable, outstanding | 1-7 rating |

The foreman's performance evaluation has been classified in six categories, and the overall performance evaluation (e.g. foreman's skills level) is giving by the combination of these six categories. The outputs also are expressed in linguistic and numeric scales as it is described in Table 3-8.

Table 3-8: Output Factors

| Factor No. | Name of Factor | Linguistic Descriptors | Numerical Scale |
|---|---|---|---|
| Output # 1 | Safety Level Assessment | Poor, acceptable, outstanding | 1-7 rating |
| Output # 2 | QA/QC Level Assessment | Poor, acceptable, outstanding | 1-7 rating |
| Output # 3 | Leadership and Supervision Level Assessment | Poor, acceptable, outstanding | 1-7 rating |
| Output # 4 | Employee Relations Level Assessment | Poor, acceptable, outstanding | 1-7 rating |
| Output # 5 | Planning and Scheduling Level Assessment | Poor, acceptable, outstanding | 1-7 rating |
| Output # 6 | Administration Level Assessment | Poor, acceptable, outstanding | 1-7 rating |
| Output # 7 | Foreman's Skills Level Assessment | Very Poor, Poor, Acceptable, Good, Outstanding | 1-7 rating |

## 3.3 Configuration of the Model Factors and Model Description

At this point, a complete set of criteria for the foreman's performance evaluation has been developed based on the input and output factors identified. The inputs and outputs have been classified according to areas of responsibility and assessment groups (foreman, supervisors and peers, and crew members). A sample of the framework of the model is shown in Figure 3-1.

Figure 3-1 shows a section of the structure of the complete foreman's performance evaluation model. Based on this structure, the model works as follows:

- Input factors section: the inputs are used to evaluate the performance in each category by group of assessment (foreman, supervisors and peers, and crew members). The input factors (input variables) are described in Tables 3-1 to 3-6.
- Intermediate output/input: the intermediate outputs give the foreman's performance evaluation by each assessment group. They also are used as inputs to evaluate the overall foreman's performance evaluation by category. Each category is being evaluated by three group assessment (e.g., foreman, supervisors and peers, and crew members). More details of data collection and processing (evaluation by group assessment) are presented in Chapter 4.

- Outputs: each category output (safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration) is used as input to assess the overall foreman's performance evaluation (foreman's skill level assessment). A representation of these relationships is shown in Figure 3-2.

The model can be used in the following ways:

- To predict and evaluate the overall foreman's performance evaluation (foreman's skills level), based on the characteristics of the foreman and his environment (i.e., based on the input variables).
- To predict and evaluate the foreman's performance evaluation in each category of assessment (safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration).
- To evaluate the foreman's performance using linguistic terms supported by subjective data from the assessment groups.
- To compare the foreman's performance evaluation between different assessment groups (foreman, supervisors and peers, and crew members).
- To contrast the foreman's performance evaluation between categories (safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration).

Figure 3-1: Subdivision of the Structure of the Model of Foreman's Performance Evaluation

(Safety Section)

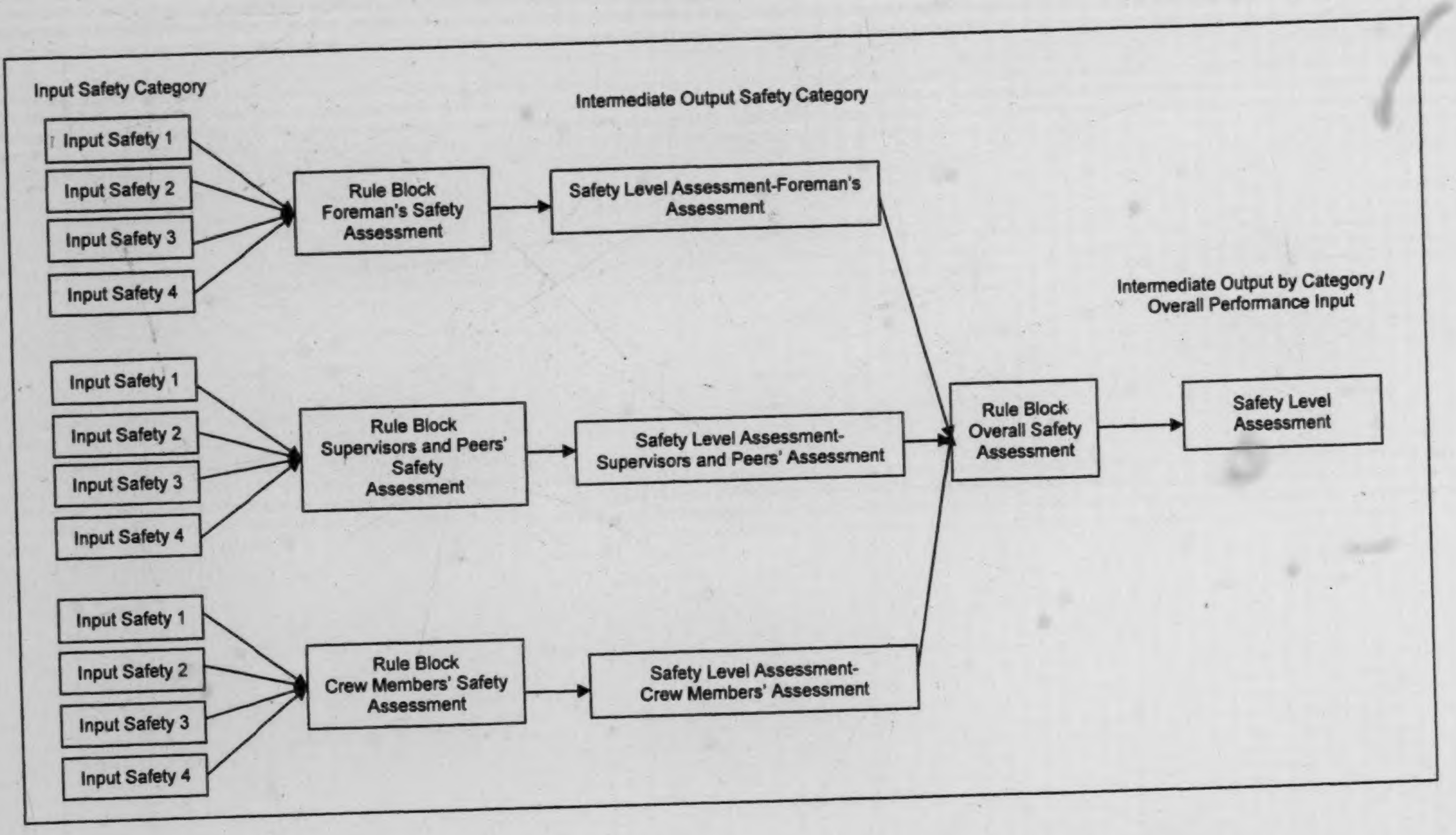
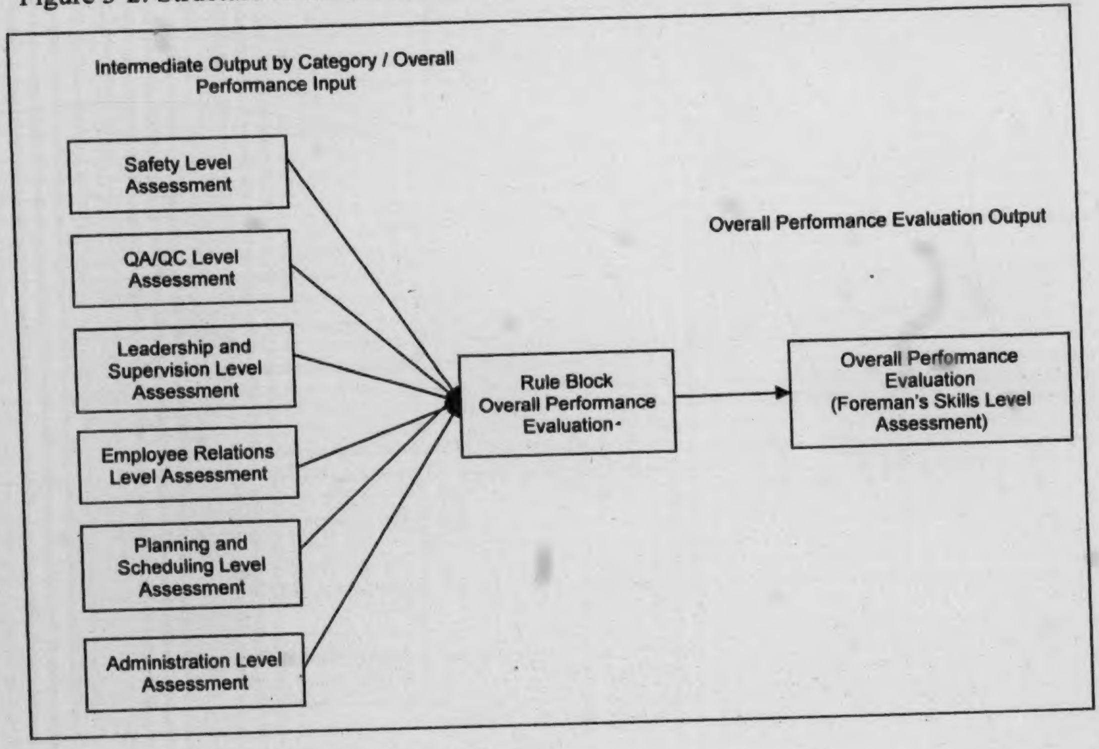

Input Safety Category
Intermediate Output Safety Category
Input Safety 1
Input Safety 2
Input Safety 3
Input Safety 4
Rule Block Foreman's Safety Assessment
Safety Level Assessment-Foreman's Assessment
Intermediate Output by Category / Overall Performance Input
Input Safety 1
Input Safety 2
Input Safety 3
Input Safety 4
Rule Block Supervisors and Peers' Safety Assessment
Safety Level Assessment-Supervisors and Peers' Assessment
Rule Block Overall Safety Assessment
Safety Level Assessment
Input Safety 1
Input Safety 2
Input Safety 3
Input Safety 4
Rule Block Crew Members' Safety Assessment
Safety Level Assessment-Crew Members' Assessment

Figure 3-2: Structure of the Model: Relationship Between Categories and Overall Output


Intermediate Output by Category / Overall Performance Input
Safety Level Assessment
QA/QC Level Assessment
Leadership and Supervision Level Assessment
Employee Relations Level Assessment
Planning and Scheduling Level Assessment
Administration Level Assessment
Rule Block Overall Performance Evaluation
Overall Performance Evaluation Output
Overall Performance Evaluation (Foreman's Skills Level Assessment)

## 3.4 Summary

The model presented in this chapter provides the basis for the fuzzy logic model used to predict and evaluate the foreman's performance. The next step is the development of the fuzzy logic model is the generation of membership functions. The generation of membership functions process is described in Chapter 5.

# CHAPTER 4 DATA COLLECTION AND PROCESSING

## 4.1 Introduction

To collect the data needed to implement and test the foreman's performance evaluation and prediction fuzzy logic model three questionnaires were designed; foreman (self-evaluation) manual, supervisors and peers manual, and crew members manual. The main goals of this survey are:

- To collect data from actual assessment groups to provide a 360° review of the foreman for the purposes of modeling.
- To identity the factors that impact directly and indirectly the foreman's performance.
- To identify responsibilities and/or duties of the foreman in his/her daily tasks to refine the input variables in the fuzzy logic model.

## 4.2 Questionnaire Design

The creation of three questionnaires was the first step in the data collection process; foreman (self-evaluation) manual, supervisors and peers manual, and crew members manual (Fayek and Poveda, 2008). These three questionnaires allow the user to have a 360° review of the foreman. The supervisors and peers manual may provides feedback from the general foremen, other foremen, superintendents, managers, and other individuals that might interact directly with the foremen in areas such as quality assurance and quality control, safety, and materials. Each of the three questionnaires contain six areas of evaluation (safety, quality assurance and quality control, leadership and supervision, employee relations, planning and scheduling, and administration) identified in the COAA industrial Construction Trades Foreman position description and supported by the literature review presented in Chapter 2 of this thesis.

Furthermore, the foreman (self-evaluation) manual contains a set of questions related to the foreman's knowledge, skills, training, education level, experience, and attitude characteristics, which are intrinsic in the six categories of responsibilities. In addition, the foreman's self-evaluation manual includes questions such as age group, construction work experience (supervisory and non-supervisory), formal education, formal training, computer skills, and informal training and experience. Lastly, each of the three questionnaires include an open question where the participants can discuss aspects of the project(s) or daily tasks that might be out of the foreman's control. These aspects may or may not affect the foreman's performance but they can be considered for future research in the area. A sample of the questionnaires is found in Appendix B: Foreman (Self-Evaluation) Manual.

### 4.2.1 The Rating Scale

Each of the six areas of responsibility (safety, quality assurance and quality control, leadership and supervision, employee relations, planning and scheduling, and administration) a number of questions. The number of questions depends on the tasks that the foreman performs according to the COAA industrial Construction Trades Foreman position description and the findings in the literature review. Figure 4-1 shows the questions for the safety area of responsibility. Also, the questions in each area have been codified; safety (S), quality control and quality assurance (Q), leadership and supervision (L), employee relations (E), planning and scheduling (P), and administration (A).

The 7-point semantic differential scale was chosen to evaluate each task. This scale contains a midpoint (4) that provides a neutral rating (e.g., neither low nor high). It is considered as positive skills values above four, and negative skills values below four. The scale of 7-point has been chosen because slightly improvements over time are easier to measure. A scale of 5-point does not provide this option without making drastic jumps from one level to the next, and a scale of 9-point is considered too tedious, boring and exhausting for the users increasing the probability of errors or bias. Another option provide in the questionnaires is the not applicable/not able to assess, which helps to determine responsibilities that are not part of the foreman's daily tasks, or an individual is unable to assess because it is not visible for a given group (e.g., crew members). It is recommended to the participants to use the N/A (not applicable) response in case they are not able to assess the foreman in any given area, rather than supply an inaccurate assessment.

| | | Skills Evaluation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Safety** | Not Applicable/ Not Able To Assess | Extremely Low | Quite Low | Slightly Low | Neither Low Nor High | Slightly High | Quite High | Extremely High |
| | **To what extent do you think the foreman:** | **N/A** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| S1. | Has a good understanding of HSE good practices and procedures? | | | | | | | | |
| S2. | Is knowledgeable in Workers' Compensation Board and insurance provisions? | | | | | | | | |
| S3. | Supports the company safety program? | | | | | | | | |
| S4. | Emphasizes safe work practices? | | | | | | | | |
| S5. | Communicates safety policies and procedures? | | | | | | | | |
| S6. | Completes initial safety and hazard assessments (e.g., FLRAs)? | | | | | | | | |
| S7. | Develops safe work plans for your crew members? | | | | | | | | |
| S8. | Correctly answers technical safety questions from your crew? | | | | | | | | |
| S9. | Conducts safety tool box meetings? | | | | | | | | |
| S10. | Identifies and arranges for crew safety training? | | | | | | | | |
| S11. | Participates in safety/incident investigations and reviews? | | | | | | | | |
| S12. | Completes his/her incident and other safety reports? | | | | | | | | |
| S13. | Enforces the company drug and alcohol policy? | | | | | | | | |

FLRA = Field Level Risk Assessment
HSE = Health, Safety, and Environment

Figure 4-1: Questionnaire for Safety Area of Responsibility

## 4.3 Survey Methodology

To test the questionnaires and collect the data necessary to develop the fuzzy logic model an industrial construction contractor in Edmonton supported a pilot in its facilities; fabrication shop and module yard. Since the staff in the company is considered long-term workers, meaningful data were collected. The total of participants in the survey is shown in Table 4-1.

Table 4-1: Number of Participants in Foreman's Evaluation

| **Position** | **Number of Participants** |
|---|---|
| Foreman | 17 |
| General Foreman | 8 |
| Superintendents | 5 |
| QA/QC | 3 |
| Safety | 2 |
| Materials | 4 |
| Crew Members | 140 |

A few steps were necessary to introduce the questionnaires to the group of foremen, supervisors and peers, and crew members. How to complete the questionnaires, purpose of the study, and expected feedback was explained in a number of presentations directed to all the participants including management. In order to get a high response rate the participants were advised that the study was confidential and the results were not going to be used for disciplinary action. But, it was promised to give a confidential feedback to each foreman to identify his/her areas of strengths and weaknesses in order to gain further training and/or mentoring.

The survey was completed at the end of September 2007. A total of 230 questionnaires were completed distribute: 17 foreman (self-evaluation) manuals, 73 Supervisors and Peer manuals, and 140 Crew members manuals.

The percentages of response in both sections of the company (e.g., fabrication shop, module yard) had high response rate: the supervisors and peers, and crew members group assessments had a 100% participation, and the foreman group assessment has 91.67 % participation because of all existing foreman in the company only one refused to participate in the study, however his crew members responded the questionnaires. The questionnaires were administered in person to guarantee not only the confidentially of the responses but also to a high response rate, which contrast with from mail-out surveys that usually have response rates of 20% to 30% (Ahmad and Minkarah, 1998).

### 4.3.1 Introduction of the Tool

It is believed that more accurate and precise responses are obtained if the participants feel confident and comfortable at the moment of data collection, for that the participants have to be approached with certain grade of expertise and prudence. To obtain an active participation the following steps were used to achieve this goal.

- **Step 1**. Become familiar with the company, its processes, and its personnel since we were an outside party to the company. There was a need for getting involved with the workers, being friendly and approachable but at the same time demonstrate some authority in order to administer the questionnaires efficiently.

- **Step 2**. Management took ownership sending out a memo describing the purposes of the tool. The main reason is to give the participants some time to become familiar with the questionnaires and the reason behind the study.

- **Step 3.** The next step was to hold information sessions to introduce the questionnaires and methodology of the study to each foreman, his crew members, his supervisors and management. Also, in these information sessions the anonymity of the responses from supervisors and peers and crew members was addressed. The expected feedbacks for each foreman and the company were pointed as well.

### 4.3.2 Identification of Supervisors and Peer and Crew Members

To identify the supervisors and peers for each foreman, at the end of the information sessions each foreman had the chance fill up the form shown in Appendix C. Although the company had identify for each foreman his supervisors and peers, it is necessary to give him the freedom to provide the names of them. If the foreman has quite few peers –which is usually the case in the construction industry- he had to mention two or three who are most aware of his responsibilities and work most closely.

The author suggests that the crew members participating in the foreman's evaluation must know the foreman for a period of minimum of four weeks. Additionally, it is recommend that the foreman had been with the company for a certain period of time to make sure that he knows the company practices and policies, develop an effective relationship with his crew members, and get comfortable with the work environment.

### 4.3.3 Administration of Questionnaires

After having the information sessions, each group (foremen, supervisors and peers, and crew members) had the opportunity to respond the questionnaires separately from the other groups with the purpose to eliminate any chance of biased responses, make the participants more comfortable, and guarantee the confidentiality of the study. The duration for completing the questionnaires varied for each group, the average durations were:

- Foreman (self-evaluation) manual: 45 minutes
- Supervisors and Peers manual: 30 minutes per foreman they were assessing
- Crew members manual: 30 minutes per foreman they were assessing

## 4.4 Data Processing Procedure

The survey consists of six categories (safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration) evaluated by each group assessment: foreman (self-evaluation), supervisors and peers, and crew members. The number of individuals in each group may vary, however the foreman (self-evaluation) is integrated only by the foreman him/herself. Each category contains a number of questions representing the assessment for the tasks that the foreman must perform in his daily basis. It was decided to weight all the questions equally in each given category to derive a mean assessment of the foreman's skills by respondent.

In the statistical model the first step in the data analysis was to develop descriptive statistics of each foreman's performance in each of the 6 areas of responsibilities. The statistics included the mean, median, and standard deviation (amongst others). The descriptive statistics were then compiled separately for each group assessment (e.g., foreman, supervisors and peers, and crew members) for each foreman using the mean assessments of each individual respondents in the group, as shown in Table 4-2. An overall mean assessment for each foreman for a given area of responsibility was obtained using a weighted average of the mean of each group's assessment, Appendix D shows the results for each category using the statistical model. An overall company mean and median assessment (based on all foreman and all groups of respondents) was calculated for each are of responsibility, by taking the mean and median value of all foreman's overall means.

In the fuzzy logic model, the questions were re-grouped following a series of criteria (section 3.1.2 shows the criteria used to re-group the questions), although each question represents a particular foreman's task/responsibility/duty, some similarities were identified between the questions. The input variables for each group assessment was calculated by adding the responses of the participant and dividing by the number of questions (mean), subsequently the value of that variable for that particular group assessment would be calculated by adding the means and diving by the number of participants (mean of the means). Appendix E shows the numeric results for each variable in each category for each group assessment. Grouping the questions not only simplify the number of input variables but also give the manageability factor to the fuzzy logic model, Appendix F shows the grouped questions by criteria for each category.

Table 4-2: Sample Statistical Analysis for a Given Foreman by Crew Members in QA/QC Area of Responsibility

| **Response** | **Question No** Q1 | Q2 | Q3 | Q4 | Q5 | Q6 |
|---|---|---|---|---|---|---|
| Supervisor 1 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 2 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 3 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 4 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 5 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 6 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 7 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 8 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 9 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |
| Supervisor 10 | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] | [redacted] |

| **Mean by Supervisor** | |
|---|---|
| Supervisor 1 | 3.00 |
| Supervisor 2 | 2.67 |
| Supervisor 3 | 3.83 |
| Supervisor 4 | 4.33 |
| Supervisor 5 | 4.67 |
| Supervisor 6 | N/A |
| Supervisor 7 | N/A |
| Supervisor 8 | N/A |
| Supervisor 9 | N/A |
| Supervisor 10 | N/A |

| **Statistics** | |
|---|---|
| **Mean** | 3.70 |
| **Standard Error** | 0.43 |
| **Median** | 3.83 |
| **Mode** | N/A |
| **Standard Deviation** | 0.85 |
| **Sample Variance** | 0.73 |
| **Kurtosis** | -2.30 |
| **Skewness** | -0.19 |
| **Range** | 2.00 |
| **Minimum** | 2.67 |
| **Maximum** | 4.67 |
| **Sum** | 18.50 |
| **Count** | 5.00 |

## 4.5 Summary

This chapter presented the survey technique used to collect actual data for modeling purposes. The data collected was used to test the fuzzy logic model, also to develop the fuzzy membership functions and to generate the If-Then rules. Once the model was developed it was tested comparing the results obtained from the statistical model (Fayek and Poveda, 2008) and the fuzzy logic model. The following two chapters describe these procedures: development of fuzzy expert system (generation of membership functions, development of fuzzy expert rules), and model validation and sensitivity analysis.

# CHAPTER 5 DEVELOPMENT OF FUZZY EXPERT SYSTEM FOR PREDICTING AND EVALUATING FOREMAN'S PERFORMANCE

## 5.1 Introduction

This chapter describes the development of the fuzzy expert system used to model the performance evaluation and prediction of construction trades foremen. It describes the development of membership functions, fuzzy rules and, the fuzzy inference mechanism for the performance evaluation model that was developed in this study. The chapter also covers the procedures to develop fuzzy rules using Fuzzy-Tech (INFORM GmbH., 2008).

The development of the fuzzy model was limited to one data set, which was used to validate the membership functions and fuzzy rules. In order to overcome limited data the author made a series of assumptions explained in further sections of this chapter, and a high accuracy needed to be demonstrated in the validation process; measured by having the percentage difference between the statistical and fuzzy logic model. The foreman evaluation data had in total 17 data points including 17 foremen, 140 crew members, 22 supervisors (general foremen, superintendents, QA/QC, safety, and materials).

The major problem that was encountered in trying to develop the fuzzy logic model in this study was the large number of input factors that had to be considered in each category in the performance evaluation model. Seventy-seven original input factors were considered in the fuzzy logic model. The selection of the 77 inputs factors was based on the COAA industrial Construction Trades Foreman position description and supported by the literature review presented in Chapter 2 of this thesis. At the early stage of the model development, all 77 factors were considered to develop the fuzzy logic model.

However, it was found that this was not a practical procedure solution due to the problem of exponential growth of rules and consequently, generation of a very large rule base. Those 77 inputs factors are divided in 6 categories as follow:

- Safety: 13 input factors

- QA/QC: 6 input factors
- Leadership and Supervision: 20 input factors
- Employee Relations: 12 input factors
- Planning and Scheduling: 15 input factors
- Administration: 11 input factors

For example, in case of the safety area, if a rule base is to be created for an expert system having 13 input factors, with each input factor having three membership functions, the number or rules that would be generated is $3^{13}$ (i.e., approximately 1,594,323 rules). To overcome the rule growth problem the model was readjusted to regroup the input factors of the model for each category. The regrouped input factors and the criteria used are shown in Appendix E. The model was developed based on this new structure, which reduced the number of input factors and solved the problem of growth of rules. Table 5-1 shows the input factors for each category used in the model and for which data were collected. The total of input factors by category after regrouping them is as follow:

- Safety: 4 input factors
- QA/QC: 2 input factors
- Leadership and Supervision: 5 input factors
- Employee Relations: 3 input factors
- Planning and Scheduling: 4 input factors
- Administration: 3 input factors

Table 5-1: Input Factors by Category

| Category | Input Variables |
|---|---|
| Safety | Technical Knowledge |
| | Company Policies |
| | Safety Procedures |
| | Safety Development by crew |
| QA/QC | Inspection and Resolve QA/QC problems |
| | QA/QC Specifications |
| Leadership and Supervision | Oral and Written Communication Skills |
| | Knowledge of Crew and Scope of Work |
| | Responsibility at Work and Work Ethic |
| | Decision Making Abilities |
| | Team Work |
| Employee Relations | Crew Issues |
| | Disciplinary Action |
| | Company Policies |
| Planning and Scheduling | Meeting Weekly Targets/Productivity |
| | Communication to Crew Members/Others Crews |
| | Planning Abilities |
| | Workface/Detailed Planning |
| Administration | Documentation |
| | Communication Skills |
| | Logistics |

## 5.2 Data Extraction

The data used in developing the fuzzy logic model to evaluate and predict the foreman's performance were collected using self-completed questionnaires in each one of the six categories (safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration). The performance evaluation form used by Fayek and Poveda (2008) to collect performance evaluation data was structured to collect subjective data from each participant in the assessment groups.

For this study, the data needed to develop the fuzzy logic was extracted from the data set in Fayek and Poveda (2008). It includes all data for the 21 input factors in the six different categories (safety, QA/QC, leadership and supervision, employee relations, planning and schedule, and administration) involved in the foreman's performance evaluation.

For each of the input and the output factors involved in the foreman's performance evaluation, three membership functions were developed, such as poor, acceptable, and outstanding, with the exception of the output factor named foreman's skill assessment (e.g., final output), obtained using the performance evaluation in each category and combining them to achieve an overall view of the foreman performance, which had five membership functions, such as very poor, poor, acceptable, good, and outstanding.

The number of membership functions and their names (e.g., poor, acceptable, and outstanding) were designed taking into consideration the manageability factor of the model and the compatibility of linguistics measure for which the model was developed (e.g., performance evaluation). The manageability factor refers to the number of rules that can be generated by having a larger number of membership functions, the more membership function are being used the more rules are generated. The compatibility of linguistic measure refers to the use of appropriate linguistic terms to measure performance, it would not be appropriate to name the membership functions; cold, warm, and hot. The linguistic terms needed to be selected for the users (industry, engineers, human resources managers, employees) to understand the meaning of each term. Tables 5-2, 5-3 and 5-4 show the membership functions used for each variable (e.g., inputs, intermediate output/input, final outputs) in the model.

The data extracted were used to test the fuzzy logic model that was developed (e.g., model validation and sensitivity analysis). The tests were done in two stages for the complete model; model validation and sensitivity analysis. The first stage (e.g., model validation) was done in one trial, and the second stage (e.g., sensitivity analysis) was done in eight trials. The trials were carried out to obtain the best fuzzy logic model, in terms of numerical and linguistic accuracies of the output for each system. Some adjustments were made in the base model (e.g., model validation) changing some characteristics. Three main groups of changes can be identified during this stage; membership function shapes, defuzzification methods, implication and aggregation methods.

Table 5-2: Membership Functions for the Input Variables (Base Case)

| Input Factor | MBF | Shape |
|---|---|---|
| Technical Knowledge | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Company Policies | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Safety Procedures | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Safety Development by crew | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Inspection and Resolve QA/QC problems | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| QA/QC Specifications | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Oral and Written Communication Skills | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Knowledge of Crew and Scope of Work | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Responsibility at Work and Work Ethic | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Decision Making Abilities | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Team Work | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Crew Issues | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Disciplinary Action | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Company Policies | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Meeting Weekly Targets/Productivity | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Communication to Crew Members/Others Crews | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |

Table 5-2: Membership Functions for the Input Variables (Base Case)

| | | |
|---|---|---|
| **Planning Abilities** | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| **Workface/Detailed Planning** | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| **Documentation** | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| **Communication Skills** | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| **Logistics** | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |

Table 5-3: Membership Functions for the Intermediate Outputs/Inputs

| Input Factor | MBF | Shape |
|---|---|---|
| Safety Level Assessment –Foreman Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Safety Level Assessment –Supervisors and Peers Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Safety Level Assessment –Crew Members Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| QA/QC Level Assessment –Foreman Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| QA/QC Level Assessment –Supervisors and Peers Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| QA/QC Level Assessment –Crew Members Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Planning and Scheduling Level Assessment –Foreman Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Planning and Scheduling Level Assessment –Supervisors and Peers Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Planning and Scheduling Level Assessment –Crew Members Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Employee Relations Level Assessment –Foreman Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Employee Relations Level Assessment –Supervisors and Peers Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Employee Relations Level Assessment –Crew Members Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Leadership and Supervision Level Assessment –Foreman Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Leadership and Supervision Level Assessment –Supervisors and Peers Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Leadership and Supervision Level Assessment –Crew Members Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Administration Level Assessment –Foreman Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |

Table 5-3: Membership Functions for the Intermediate Outputs/Inputs

| | | |
|---|---|---|
| Administration Level Assessment –Supervisors and Peers Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Administration Level Assessment –Crew Members Category | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |

Table 5-4: Membership Functions for the Final Outputs

| Input Factor | MBF | Shape |
|---|---|---|
| Safety Level Assessment | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| QA/QC Level Assessment | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Leadership and Supervision Level Assessment | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Employee Relations Level Assessment | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Planning and Scheduling Level Assessment | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Administration Level Assessment | Poor | Trapezoidal |
| | Acceptable | Triangular |
| | Outstanding | Trapezoidal |
| Skills Level Assessment (Overall Assessment) | Very Poor | Trapezoidal |
| | Poor | Triangular |
| | Acceptable | Triangular |
| | Good | Triangular |
| | Outstanding | Trapezoidal |

## 5.3 Development of Membership Functions

### 5.3.1 Introduction

The **membership function** of a fuzzy set is a generalization of the indicator function in classical sets. In fuzzy logic, it represents the degree of truth as an extension of valuation. Degrees of truth are often confused with probabilities, although they are conceptually distinct, because fuzzy truth represents membership in vaguely defined sets, not likelihood of some event or condition. The output of a membership function is called the degree of membership, this value is always limited to between 0 and 1, and it is also known as a membership value or membership grade. For a continuous variable, this degree is expressed by a function called a membership function. The membership value, $\mu_x$, corresponding to a particular element, x, in the universe of discourse **U**, depends on the shape of the membership function and varies between 0 and 1. The degree of belief that an element x, in the universe of discourse, **U**, is well represented by a linguistic concept, is depicted by the membership function. This degree of belief is measured in terms of the membership value, $\mu_X$. For example, the membership function $\mu_A(x)$ describes the membership of the elements $x$ of the base set $X$ in the fuzzy set $\mathcal{A}$, whereby for $\mu A(x)$ a large class of functions can be taken. Reasonable functions are often piecewise linear functions, such as triangular or trapezoidal functions. The grade of membership $\mu_A(x_o)$ of a membership function $\mu_A(x)$ describes for the special element $x = x_o$, to which grade it belongs to the fuzzy set $\mathcal{A}$. This value is in the unit interval [0,1]. Of course, $x_o$ can simultaneously belong to another fuzzy set $\mathcal{B}$, such that $\mu_B(x_o)$ characterizes the grade of membership of $x_o$ to $\beta$. Figure 5-1 shows this membership functions.

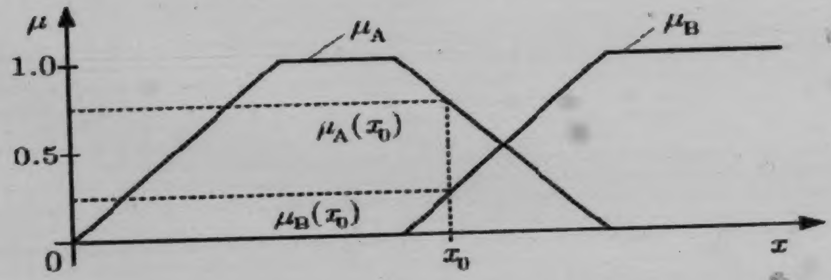


Figure 5-1: Membership Grades of $x_o$ in the Sets $\mathcal{A}$ and $\mathcal{B}$: $\mu_A(x_o)$ =0.75 and $\mu_A(x_o)$ =0.25

To develop a model using fuzzy logic involves the generation of membership functions for all the input and output factors in the model. After identifying and classifying the factors involved in the foreman's performance evaluation supported by the COAA construction trades foreman job description and literature review, the next step in the development of the fuzzy expert system, is the development of membership functions for all the input and output factors, as well as for the intermediate output/input factors.

Reviewing the literature existing on the topic of performance evaluation personnel (e.g., construction trades, supervisors, and general foreman) reveals that no fuzzy logic model exists for modeling construction trades foremen performance neither to evaluate nor predict their performance. The development of membership functions depends on the availability of large data sets that are not easy to obtain in the construction industry. In this study, subjective data were collected and used; as described in previous chapter, to develop a model to evaluate and predict the foreman's performance. Existing literature revealed the different techniques that are available for developing membership functions (Dissanayeke, 2006). Most of these techniques require the use of a small number of input factors and large data sets in order to train, test, and validate the membership functions (Sun, 2000). In this study, the author had only a limited data set with which to validate the not only the membership functions but also the rule base and the output values, and the structure of the model.

The literature review also shows that no specific technique is applied to evaluate or predict performance; that is, either because of lack of standard criteria to do so, or the number of complex factors involved in it. Consequently, one of the goals of this research is to develop a technique to evaluate performance using fuzzy logic technique based on objective data that can be used not only to evaluate performance but also to predict it. Defining membership functions on the basis of objective data is a first step towards developing membership functions that are widely applicable in a given context. In the previous chapter was described the methodology to collect the data required to implement and test the membership functions in the fuzzy logic model. Each input factor in the model can be described in terms of three linguistic terms, each of which is represented by a membership function

### 5.3.2 Assumptions Used in Developing Membership Functions

The following assumptions were made to develop the membership functions used in this study:

- There are various statistical techniques for determining the membership functions. Watanabe (1979) asserts that these fall into two broad categories: use of frequencies or by direct estimation. Put simply, the frequency method obtains a membership function by measuring the percentage of people in a group (typically experts in a particular domain) who answer yes to a question about whether an object belongs to a particular set. Direct estimation methods take a different approach by asking experts to grade an event on a scale; the development of the fuzzy logic model to predict and evaluate the foreman's performance has used this method to determine the membership functions. Other methods for determining membership functions are automatic methods such as genetic algorithms and neural networks (Dissanayake, 2006).

- "Theoretically, fuzzy numbers can take various shapes. In modeling real-life problems, however, linear approximations such as the trapezoidal and triangular fuzzy members are frequently used" Lorterapong and Moselhi (1996), the author simplified this problem using two common membership functions shapes (triangular and trapezoidal) to model each input and output factor in the model. Another reason to choose these two shapes is that the author believes that they represent the trend of the data collected, usually the responses obtained in the evaluation process are located in three different areas in the scale; lowest scores between 1 to 3, a medium score of 4, and/or high scores between 5 to 7. It was found that particular group assessments have a general consent of their foremen, this was indicated by getting the most responses in a particular section of the scale representing the trend of the data. The triangular shape can deal with peaks, and the trapezoidal one can handle ranges of numbers. The trapezoidal fuzzy number can be represented by a quadruple (a, b, c, d), while the triangular fuzzy number is a special case of the trapezoidal shape, with b=c. Figure 5-2 represent the triangular and trapezoidal membership functions.

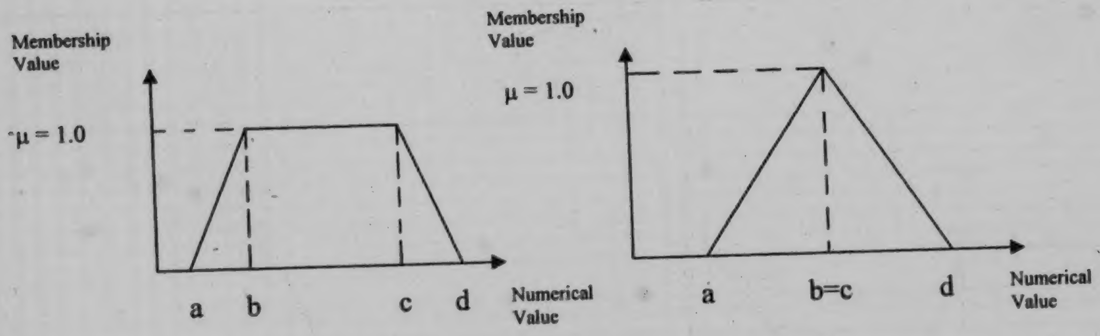


Figure 5-2: Trapezoidal and Triangular Membership Function

- A special property of two convex fuzzy sets, say *A* and *B,* is that the intersection of these two convex fuzzy sets is also a convex fuzzy set, as shown in Figure 5-3. That is, for *A* and *B*, which are both convex, $A \cap B$ is also convex.

  The crossover points of a membership function are define as the elements in the universe for which a particular fuzzy set *A* has values equal to 0.5, i.e., for which $\mu_A(x) = 0.5$. The input and intermediate output/inputs variables in the model have two crossover points; one intersect the poor and acceptable membership function at the value of 3, this indicates that if an individual gets an evaluation of 3, to some extent his/her performance is poor and to some extend his/her performance is acceptable, this degree of extent is called "degree of membership". The other crossover point was indicated at 5, using the same rationale, if an individual gets a performance value of 5, this indicated that his/her performance is acceptable to some extent and it is also outstanding to some extent.

  The height of a fuzzy set *A* is the maximum value of the membership function, i.e., hgt (*A*) = max $\{\mu_A(x)\}$. If the hgt (*A*) < 1, the fuzzy set is said to be subnormal. The hgt (*A*) may be viewed as the degree of validity of credibility of information expressed by *A* (Klir and Yuan, 1995). The totally membership functions used in the model have the characteristic of normal, which means hgt (*A*) = 1.

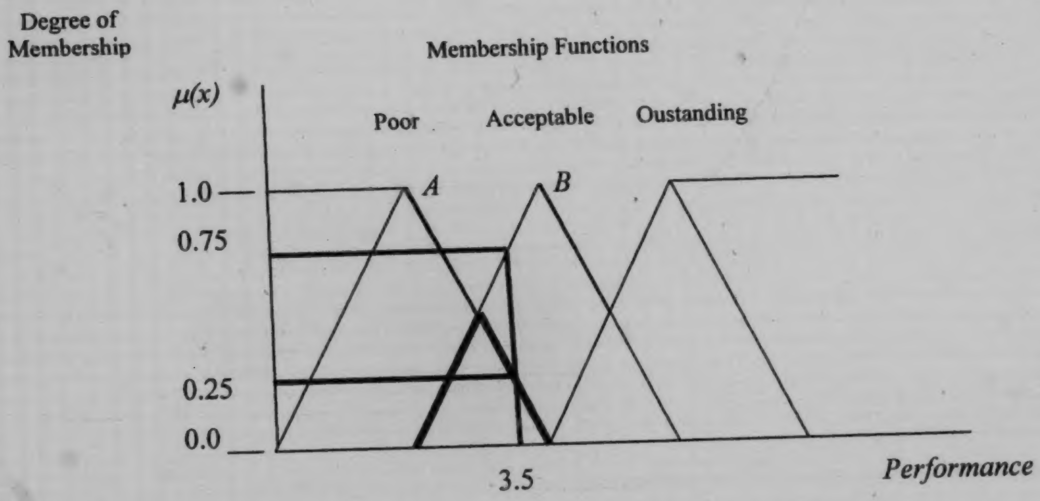

Degree of Membership
Membership Functions
$\mu(x)$
Poor
Acceptable
Oustanding
A
B
1.0
0.75
0.25
0.0
3.5
Performance

Figure 5-3: Intersection of Two Convex Fuzzy Sets

- The advantage of simplicity and efficiency with respect to computability were the main reasons for choosing triangular, trapezoidal and crisp membership functions for the input and output factors. These reasons are discussed in Juang et al (1992). In order to achieve as much overlap as possible among the membership functions, 2 out of the 4 membership functions in each input factor, are trapezoidal in shape. Figure 5-4 shows the combination of triangular and trapezoidal shapes used in the fuzzy logic model. A crisp membership function was used to represent the N/A (e.g., not applicable) values.

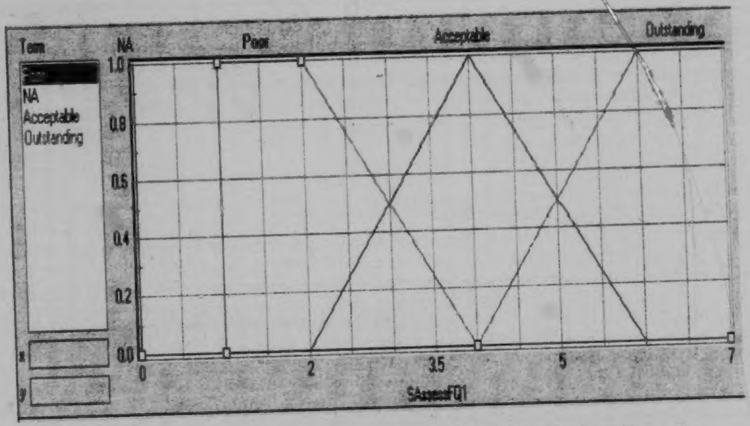

Term
Poor
NA
Acceptable
Outstanding
x
y
NA
Poor
Acceptable
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
SAssessFQ1

Figure 5-4: Membership Functions Used in Safety Inputs

- Only 1 output (overall foreman's skill level) has five membership functions, a difference from the other outputs (intermediate and final) with only three membership functions. Table 5-3 and 5-4 illustrate the membership functions used for each output in the fuzzy logic model. This allows the user to obtain a more detailed result of the overall performance evaluation/prediction, and measure improvement over time. Figure 5-5 shows the overall foreman's skills level output and its membership functions.

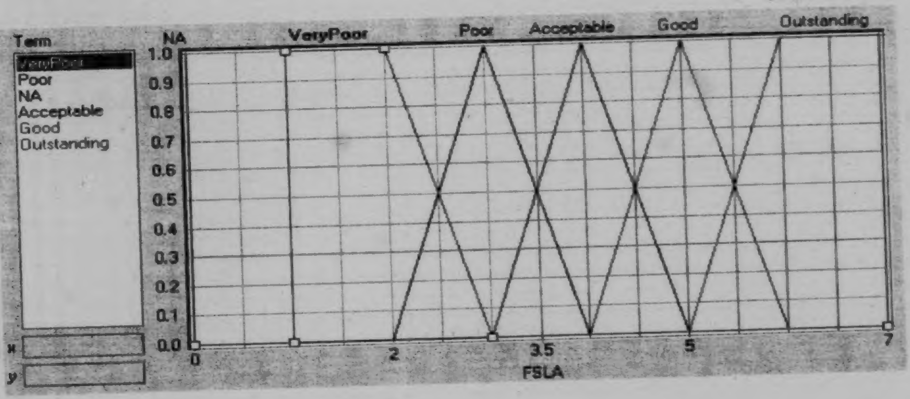

Term
VeryPoor
Poor
NA
Acceptable
Good
Outstanding
x
y
NA
VeryPoor
Poor
Acceptable
Good
Outstanding
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
2
3.5
5
7
FSLA

Figure 5-5: Membership Functions Used in Overall Foreman's Skills Level Output

- The author assumes that the first and third membership function (e.g., poor, outstanding) always has a trapezoidal shape, so that values of performance between 1 to 2 will be considered to have a degree of membership of 1. Further, any performance values between 6 to 7 will have a degree of membership of 1. The middle membership function has a triangular shape with a maximum of degree of membership of 1 in its peak.

- The performance evaluation was divided into 7 intervals. Point 1 represents extremely low and point 7 represents extremely high. Consider a set of linguistic expressions that classify "performance evaluation" into "Poor", "Acceptable", and

"Outstanding". Assume that Figure 5-1 represents the membership functions for the concept of performance evaluation (input and intermediate outputs). The Fuzzy membership functions of the qualitative expressions for the inputs and intermediate inputs/outputs (Figure 5-1) are assume as follows:

Poor: $\mu = 1,\ 1 \le x \le 2$

$\mu = (2 - 0.50 * x), 2 \le x \le 4$

$\mu = 0,\ x > 4$

Acceptable: $\mu = 0,\ x \le 2$

$\mu = 0.50 * (x - 2), 2 \le x \le 4$

$\mu = 0.50 * (4 - x) + 1, 4 \le x \le 6$

$\mu = 0, x > 6$

Outstanding: $\mu = 0, x \le 4$

$\mu = 0.50 * (x - 4), 4 \le x \le 6$

$\mu = 1, 6 \le x \le 7$

And the fuzzy membership function of the qualitative expressions for the overall output (figure 5-2) is assumed as follow:

Very Poor: $\mu = 1,\ 1 \le x \le 2$

$\mu = (3 - 1 * x), 2 \le x \le 3$

$\mu = 0,\ x > 3$

Poor: $\mu = 0,\ x \le 2$

$\mu = 1 * (x - 2), 2 \le x \le 3$

$\mu = 1 * (3 - x) + 1, 3 \le x \le 4$

$\mu = 0, x > 4$

Acceptable: $\mu = 0,\ x \le 3$

$\mu = 1 * (x - 3), 3 \le x \le 4$

$\mu = 1 * (4 - x) + 1, 4 \le x \le 5$

$\mu = 0, x > 5$

Good: $\mu = 0, \ x \le 4$

$\mu = 1 * (x - 4), 4 \le x \le 5$

$\mu = 1 * (5 - x) + 1, 5 \le x \le 6$

$\mu = 0, x > 6$

Outstanding: $\mu = 0, x \le 5$

$\mu = 1 * (x - 5), 5 \le x \le 6$

$\mu = 1, 6 \le x \le 7$

- The number of input factors vary for each category (e.g., safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration) depending on the criteria used to classify the factors involved in the foreman's performance; however, every input factor has 3 membership functions (e.g., poor, acceptable, and outstanding).

- Each of the intermediate outputs was developed with 4 membership functions (e.g., N/A, Poor, Acceptable, and Outstanding). These intermediate outputs represent each group participating (e.g., foreman, supervisors and peers, and crew members) in the assessment of the foreman performance.

- Although the base case model was done with a combination of triangular and trapezoidal shapes, the model was tested making a series of membership function shape changes among others changes. The model was tested using one type of membership function a the time: triangular, S-shape, and trapezoidal. Combinations of the 3 types of shapes were used in the sensitivity analysis as well. These changes in the membership functions were made in the input and output variables to test and improve the accuracy of the model.

- The N/A (e.g., not applicable) responses were represented in the fuzzy logic model using a crisp membership function to eliminate any involvement in the results after the defuzzification process. During the sensitivity analysis the N/A membership was kept as crisp value.

## 5.4 Development of Fuzzy expert Rules

### 5.4.1 Introduction

The fuzzy rule base is a fundamental part in the creation of any fuzzy expert system, which correlates the input and output factors with If-Then rules. The If-Then rules work under the concept that for each cause there must an effect. The membership functions of the input factors represent the antecedents or premises, and the membership functions of the output factors represent the consequents or conclusions. The If-Then rules provide the logical reasoning framework for determining the output, based on values of the input factors. There are several fuzzy inference mechanisms used for reasoning; these mechanisms help to carry out the processes of aggregation, implication, fuzzification, and defuzzification.

For a two-input-one output fuzzy expert system (illustrated in Figure 5-6), the following example can be used to illustrate a fuzzy If-Then rule.

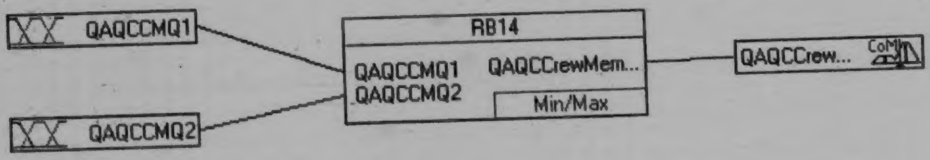


Figure 5-6: Two-Input-One Output Fuzzy Expert System Representation

Assuming that technical knowledge and supervisory experience are the input factors and administration level assessment is the output factor, a fuzzy If-Then rule can be expressed as follows:

If *technical knowledge* is poor and *supervisory experience* is outstanding, then *administration level assessment* is acceptable.

The fuzzy inference mechanism in this sample is denoted by "and", which assumes that the input factors exert equal but independent effects on the output factor.

### 5.4.2 Fuzzy Inference Mechanisms

Independently of the type of fuzzy inference system, the processing procedures are generally the same. They include five different steps in the fuzzy inference mechanisms as follow:

- **Fuzzification** is understood as the process of converting the crisp input variables to fuzzy data by determining the membership values or the degrees of belief that elements of input variables belong to fuzzy sets that are defined by membership functions.
- **Application of fuzzy operator,** having more than one input variable in the antecedent of the rule, the membership values of the input variables are combined using a fuzzy operator such as, "AND","OR" , and "NOT", to obtain a single value in the consequent of the rule. The "AND" operator has two operating methods: "MIN" operator, and "PRODUCT" operator. The "OR" operator also has two operation methods, including the "MAX" and the "PROBOR" operator. Most fuzzy logic systems use production rules to represent the relation among the linguistic variables and to derive action from the inputs. Production rules consist of a condition (IF-part) and a conclusion (THEN-part). The IF-part consist of more than one precondition linked together by linguistic conjunctions like AND or OR. Mathematical definitions of these operators will be described in the next sections of this chapter.
- **Implication** is the application of a single membership value obtained after combining membership values in the antecedent of the rule, to the fuzzy set of the output variable in the consequent of the rule. The membership function in the

consequent part of the rule is truncated (using "MIN", which truncates the output fuzzy set), or squashed down (using "PRODUCT", which scales the output fuzzy set).

- **Aggregation** occurs once for the rules in a rule base, involves combining the fuzzy output of each rule in the rule base to obtain a single fuzzy set. The aggregation computes the condition of each rule. This happens when an aggregation operator ("MAX" or "PROBOR") combines the output fuzzy set of each rule to obtain a single fuzzy set. The fuzzy operator "MAX" combines the maximum value from the output of each rule, while the operator "PROBOR" combines the algebraic sum of the output from each rule, in order to determine the single output fuzzy set.
- **Defuzzification** is the process of transforming from a fuzzy set to a crisp number. It is one of the most important operations in the theory of fuzzy sets. This operation along with the operation of fuzzification is critical to the design of fuzzy systems, as both of these operations provide a connection between the fuzzy set domain and the real valued scalar domain. There are many defuzzification methods, among which the "CENTROID" and "MAXIMUM" methods are commonly used. In the "CENTROID" method, the crisp value calculated is the center of gravity of the membership function for the input. "MAXIMUM" method involves LOM (the largest crisp value of the maximum) method, MOM (mean of the maximum value), SOM (the smallest crisp value of maximum) method.

### 5.4.3 Description of the Method of Generating If-Then Rules

Fuzzy set and fuzzy operators are the subject and verbs of fuzzy logic. Conditional statements, if-then rules are the things that make fuzzy logic useful. A single fuzzy if-then rule assumes the form:

*If x is A then y is B*

Where A and B are linguistic values defined by fuzzy sets on the ranges X and Y, respectively. The if-part of the rule "*x is A*" is called the antecedent or premise, while the then-part if the rule "*y is B*" is called the consequent or conclusion. An example of such a rule might be

*"if service is good then tip is average"*

Interpretating an if-then rule involves distinct parts. First evaluating the antecedent (which involves fuzzyfying the input and applying necessary fuzzy operators). Second, applying the results to the consequents (known as implication).

In the case of two-value or binary logic, if the premise is true, then the conclusion is true. In case of fuzzy if-then rule if the antecedent is true to some degree of membership, then the consequent part is also true to that same degree.

*In binary logic: p - > q (p and q are either true or false)*

*In fuzzy logic: 0.5 p - > q (partial antecedents apply partially)*

The antecedents of a rule can have multiple parts, for example:

*If sky is gray and wind is strong and barometer is falling then......*

In which case all the parts of the antecedent are calculated simultaneously and resolved to a single number using the fuzzy logical operators. The consequent of a rule can also have multiple parts:

If *temperature is cold then hot water valve is open and cold-water valve is shut*

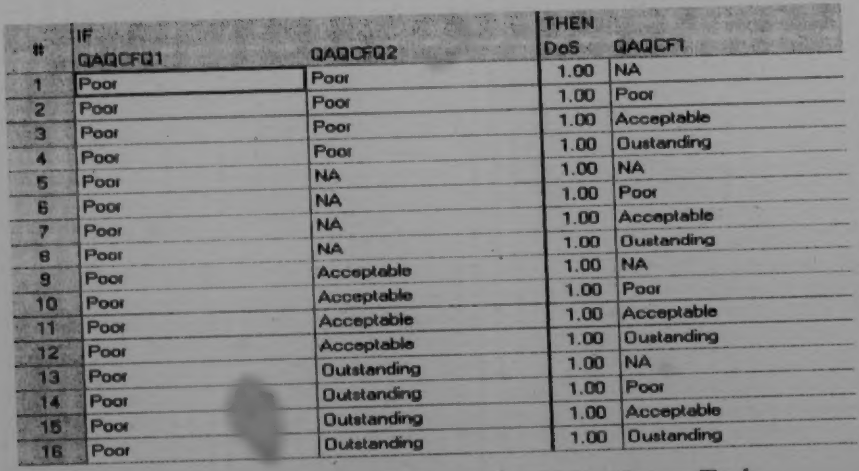
In which case all the consequences are affected equally by the results of the antecedent. The consequent specifies a fuzzy set to be assigned to the output. The implication function then modifies the fuzzy set to the degree specified by the antecedent.

Three principal methods could be employed to determine the relevant inference rules. One is to elicit them from experienced domain experts. Another is to obtain them by common sense. The third method is to elicit them from the company's historical data base. There is great limitation when choosing a method to generate If-Then rules from the limited data collected. Without sufficient data, none of the existing methods (Yager and Filev, 1994) could be properly used. Furthermore, the rule base for evaluation and predicting the foreman's performance was generated applying common sense. Moreover, the rules were constructed based on the author's logical reasoning about the way different combinations of varying degrees of input factors affect the output factors.

The rule bases were developed by iteratively correlate the input variables in a logical manner with the expected outputs. The number of rules vary for each rule block since the number of input variables differ for each group assessment (e.g., foreman, supervisors and peer, crew members) in each category to assess (e.g., safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration). The generation of If-Then rules for the fuzzy expert system in this research have been tested using real values. The detailed procedures for this technique are as follows:

- The first step is to count how many possible rules there are to maintain the completeness of the rule base. The number of rules needed in each rule base was determined automatically by the programs (Fuzzy-Tech Version 5.71g) with the exception of those block rules with more than 1000 rules. This depends also on the number of membership functions that each variable has. For example, if a model has 3 input variables and each variable has 3 membership functions, then the complete rule base will have $3^3 = 27$ rules (i.e., twenty-seven possible combinations).

- All the possible rule combinations are given automatically by the Fuzzy-Tech program by clicking on the full rule block bottom. Figure 5-7 shows a sample of rule generation for the QA/QC category of performance evaluation.



| # | IF<br>QAQCFQ1 | QAQCFQ2 | THEN<br>DoS | QAQCF1 |
|---|---|---|---|---|
| 1 | Poor | Poor | 1.00 | NA |
| 2 | Poor | Poor | 1.00 | Poor |
| 3 | Poor | Poor | 1.00 | Acceptable |
| 4 | Poor | Poor | 1.00 | Oustanding |
| 5 | Poor | NA | 1.00 | NA |
| 6 | Poor | NA | 1.00 | Poor |
| 7 | Poor | NA | 1.00 | Acceptable |
| 8 | Poor | NA | 1.00 | Oustanding |
| 9 | Poor | Acceptable | 1.00 | NA |
| 10 | Poor | Acceptable | 1.00 | Poor |
| 11 | Poor | Acceptable | 1.00 | Acceptable |
| 12 | Poor | Acceptable | 1.00 | Oustanding |
| 13 | Poor | Outstanding | 1.00 | NA |
| 14 | Poor | Outstanding | 1.00 | Poor |
| 15 | Poor | Outstanding | 1.00 | Acceptable |
| 16 | Poor | Outstanding | 1.00 | Oustanding |

Figure 5-7: Sample of Rule Generation Using Fuzzy-Tech

- If a rule has multiple outputs, but its outputs do not make sense using the criteria pre-established (logic used by the author), then this rule cannot be kept. For example, in Figure 5-7, it says that input 1 (e.g., QAQCFQ1) and input 2 (QAQCFQ2) are positively correlated to the output, and the actual rules generated by the program are:

  “If input 1 is poor and input 2 is poor, then output is N/A
  Then in that case, this rule should be ignored. If it says:
  “If input 1 is poor and input 2 is poor, then output is Acceptable
  Then in that case, this rule should be ignored. If it says:
  “If input 1 is poor and input 2 is poor, then output is Outstanding
  Then in that case, this rule should be ignored. If it says:
  “If input 1 is poor and input 2 is poor, then output is Poor
  Then this rule should be kept in the rule base

- In order to maintain the consistency of the rule base, the same premise cannot have two or more different conclusions. This inconsistency can be prevented by eliminating the rule that does not meet the pre-established criteria.

- It is assumed that all the input factors are independent and have an equal effect on the output factor, all the combinations in any order will yield the same result. For example, suppose that the actual rule says: in input 1 is poor and input 2 is acceptable, then output is poor; then, in that case, the derived rule will be : if input 1 is acceptable and input 2 is poor, then output is poor.

- The rules were tested with both operators, “AND” and “OR”. The results obtained using both operators were analyzed to determine the impact in the accuracy of the results using each one of them. The results of this operation are shown in Chapter 6 of this thesis (e.g., sensitivity analysis).

- In the event of having more than 1000 rules in a rule block the software (e.g., fuzzy-tech) does not generate the rules automatically. In this case, the author needed to do all the combinations (rules) possible manually following the same reasoning (criteria) for developing the rules generated by Fuzzy-Tech.

- The degree of support also referred as "rule weight" for each rule was 1 by default. The degree of support is the degree to which a rule is valid or plausible. Each rule is assigned a degree of support representing the individual importance of the rule, Rules themselves can be "fuzzy" -- meaning, with validity between 0 and 1. The validity of a conclusion is calculated by a linking of the validity of the entire condition with the degree of support by a composition operator. When the product operator is used as the composition operator, the degree of support reflects rule "significance". For example

  IF "Distance" = medium AND "Angle" = pos_small THEN "Power" = pos_medium

  Let degree of support = 0.8. Using the product operator for composition, the result of the rule would be:

  PROD{Degree of Validity of the Condition, Degree of Support}

  Result of the Rule (Validity of the Consequence) i.e.: PROD{0.8,0.8} = 0.64.

  This means that the result for "Power" pos_medium is a degree of validity of 0.64.

### 5.4.4 Application of the Method (Rule Generation Sample)

The technique explained in the previous section has been applied to the fuzzy expert system for predicting and evaluating the foreman's performance. An example was chosen to illustrate the technique used for developing the rules, which can be described as follow:

- Take the category of QA/QC supervisors and peers group assessment, for example. The total number of input variables is 2. Input 1 (e.g., QAQCSPQ1) has 3 membership functions, such as poor, acceptable, and outstanding, and 1 crisp value such as N/A. Input 2 (e.g., QAQCSPQ2) also has 3 membership functions, such as poor, acceptable, and outstanding, and 1 crisp value such as N/A. So the total number of possible rules for each output is 4 * 4 = 16. So the framework of the model is:

  If input 1 is (N/A, poor, acceptable, and outstanding), and input 2 is (N/A, poor, acceptable, and outstanding) then output (e.g., QAQCSP1) is (N/A, poor, acceptable, and outstanding). The computer generates automatically 64 rules since there are 4 possible outputs, making all the combination possible the total number of rules generated is 16 * 4 = 64.

- Count all the actual rules. The results are shown in Table 5-5:

## Table 5-5: Sample of Rules Derived From Actual Data-QA/QC Category

| Rule Number | Input 1 QA/QCSPQ1 | Input 2 QA/QCSPQ2 | Output QA/QCSP1 | Check Consistency |
|---|---|---|---|---|
| 1 | Poor | Poor | NA | Eliminate |
| 2 | Poor | Poor | Poor | Keep |
| 3 | Poor | Poor | Acceptable | Eliminate |
| 4 | Poor | Poor | Outstanding | Eliminate |
| 5 | Poor | NA | NA | Eliminate |
| 6 | Poor | NA | Poor | Keep |
| 7 | Poor | NA | Acceptable | Eliminate |
| 8 | Poor | NA | Outstanding | Eliminate |
| 9 | Poor | Acceptable | NA | Eliminate |
| 10 | Poor | Acceptable | Poor | Keep |
| 11 | Poor | Acceptable | Acceptable | Eliminate |
| 12 | Poor | Acceptable | Outstanding | Eliminate |
| 13 | Poor | Outstanding | NA | Eliminate |
| 14 | Poor | Outstanding | Poor | Eliminate |
| 15 | Poor | Outstanding | Acceptable | Keep |
| 16 | Poor | Outstanding | Outstanding | Eliminate |
| 17 | NA | Poor | NA | Eliminate |
| 18 | NA | Poor | Poor | Keep |
| 19 | NA | Poor | Acceptable | Eliminate |
| 20 | NA | Poor | Outstanding | Eliminate |
| 21 | NA | NA | NA | Keep |
| 22 | NA | NA | Poor | Eliminate |
| 23 | NA | NA | Acceptable | Eliminate |
| 24 | NA | NA | Outstanding | Eliminate |
| 25 | NA | Acceptable | NA | Eliminate |
| 26 | NA | Acceptable | Poor | Eliminate |
| 27 | NA | Acceptable | Acceptable | Keep |
| 28 | NA | Acceptable | Outstanding | Eliminate |
| 29 | NA | Outstanding | NA | Eliminate |
| 30 | NA | Outstanding | Poor | Eliminate |
| 31 | NA | Outstanding | Acceptable | Eliminate |
| 32 | NA | Outstanding | Outstanding | Keep |
| 33 | Acceptable | Poor | NA | Eliminate |
| 34 | Acceptable | Poor | Poor | Keep |
| 35 | Acceptable | Poor | Acceptable | Eliminate |
| 36 | Acceptable | Poor | Outstanding | Eliminate |
| 37 | Acceptable | NA | NA | Eliminate |
| 38 | Acceptable | NA | Poor | Eliminate |
| 39 | Acceptable | NA | Acceptable | Keep |
| 40 | Acceptable | NA | Outstanding | Eliminate |
| 41 | Acceptable | Acceptable | NA | Eliminate |

| | | | | |
|---|---|---|---|---|
| 42 | Acceptable | Acceptable | Poor | Eliminate |
| 43 | Acceptable | Acceptable | Acceptable | Keep |
| 44 | Acceptable | Acceptable | Outstanding | Eliminate |
| 45 | Acceptable | Outstanding | NA | Eliminate |
| 46 | Acceptable | Outstanding | Poor | Eliminate |
| 47 | Acceptable | Outstanding | Acceptable | Eliminate |
| 48 | Acceptable | Outstanding | Outstanding | Keep |
| 49 | Outstanding | Poor | NA | Eliminate |
| 50 | Outstanding | Poor | Poor | Eliminate |
| 51 | Outstanding | Poor | Acceptable | Keep |
| 52 | Outstanding | Poor | Outstanding | Eliminate |
| 53 | Outstanding | NA | NA | Eliminate |
| 54 | Outstanding | NA | Poor | Eliminate |
| 55 | Outstanding | NA | Acceptable | Eliminate |
| 56 | Outstanding | NA | Outstanding | Keep |
| 57 | Outstanding | Acceptable | NA | Eliminate |
| 58 | Outstanding | Acceptable | Poor | Eliminate |
| 59 | Outstanding | Acceptable | Acceptable | Eliminate |
| 60 | Outstanding | Acceptable | Outstanding | Keep |
| 61 | Outstanding | Outstanding | NA | Eliminate |
| 62 | Outstanding | Outstanding | Poor | Eliminate |
| 63 | Outstanding | Outstanding | Acceptable | Eliminate |
| 64 | Outstanding | Outstanding | Outstanding | Keep |

- Check the consistency of the rule. For example, rules 1, 2, 3, and 4 conflict. According to the pre-established criteria and the expected output rule 2 should be kept. Apply the same procedure and logic for the rest of the rules.

- Based on the number of membership function, some rules are combined to reflect the combined membership functions, 16 would be the expected total of rules to be kept. Table 5-6 shows the remaining rules for this sample.

Table 5-6: Actual Remaining Rules

| Rule Number | Input 1 QA/QCSPQ1 | Input 2 QA/QCSPQ2 | Output QA/QCSP1 |
|---|---|---|---|
| 1 | Poor | Poor | Poor |
| 2 | Poor | NA | Poor |
| 3 | Poor | Acceptable | Poor |
| 4 | Poor | Outstanding | Acceptable |
| 5 | NA | Poor | Poor |
| 6 | NA | NA | NA |
| 7 | NA | Acceptable | Acceptable |
| 8 | NA | Outstanding | Outstanding |
| 9 | Acceptable | Poor | Poor |
| 10 | Acceptable | NA | Acceptable |
| 11 | Acceptable | Acceptable | Acceptable |
| 12 | Acceptable | Outstanding | Outstanding |
| 13 | Outstanding | Poor | Acceptable |
| 14 | Outstanding | NA | Outstanding |
| 15 | Outstanding | Acceptable | Outstanding |
| 16 | Outstanding | Outstanding | Outstanding |

- The rule base for this sample is now complete.

After generating the membership functions and the fuzzy rule blocks, the next step is to validate and test the accuracy of the model (e.g., sensitivity analysis). Table 5-7 resumes the number of rules used in the fuzzy logic model and Table 5-8 shows the characteristics of the model.

Table 5-7: Rules in Each Block Rule of the Fuzzy Logic Model

| Final Output | # of Rules | Category | # of Rules | Group Assessment | # of Rules |
|---|---|---|---|---|---|
| Foreman's Skills Level | 730 | Safety | 64 | Foreman | 256 |
| | | | | Supervisors and Peers | 256 |
| | | | | Crew Members | 256 |
| | | QA/QC | 64 | Foreman | 16 |
| | | | | Supervisors and Peers | 16 |
| | | | | Crew Members | 16 |
| | | Leadership and Supervision | 64 | Foreman | 1024 |
| | | | | Supervisors and Peers | 1024 |
| | | | | Crew Members | 1024 |
| | | Employee Relations | 64 | Foreman | 64 |
| | | | | Supervisors and Peers | 64 |
| | | | | Crew Members | 64 |
| | | Planning and Scheduling | 64 | Foreman | 256 |
| | | | | Supervisors and Peers | 256 |
| | | | | Crew Members | 256 |
| | | Administration | 64 | Foreman | 64 |
| | | | | Supervisors and Peers | 64 |
| | | | | Crew Members | 64 |

Table 5-8: Fuzzy Logic Model Characteristics

| | |
|---|---|
| Input Variables | 63 |
| Output Variables | 25 |
| Intermediate Variables | 24 |
| Rule Blocks | 25 |
| Rules | 11577 |
| Membership Functions | 450 |

## 5.5 Summary

In this chapter, a description of the methodology to develop the membership functions and rule bases for the fuzzy logic model for predicting and evaluating the foreman's performance was presented. The input variables were classified according to the category to evaluate and their impact in the intermediate outputs. Each input, intermediate and final output variable is presented with its respective linguistic descriptor used to develop the membership functions for the model. A number of assumptions were made to develop the membership functions, and the basis for using them in the model were explained in detail. Triangular and trapezoidal membership functions shapes were generated for the base case, but other membership functions shapes (S-shapes) to test the accuracy of the membership function shape (sensitivity analysis).

The second part of this chapter explains the development of the rule base for the fuzzy logic model. The inference mechanisms in developing the rule base were outlined in the chapter, and a full description of the methodology to develop the If-Then rules was presented.

The next chapter describes the testing of the fuzzy logic model using different combinations of membership shapes, defuzzification methods, and implication/aggregation methods to make comparisons of the results expected in each case and improve the accuracy of the model.

# CHAPTER 6 MODEL VALIDATION AND SENSITIVITY ANALYSIS

## 6.1 Introduction

The last stage in developing the fuzzy logic model to evaluate and predict the foreman's performance consists of two processes: model validation and model sensitivity analysis. The accuracy of the model developed was determined by testing it with the data collected in previous stages of the study.

Once the criteria are set up to model the membership functions and to develop the rule bases, the accuracy of the model needs to be validated and tested (e.g., sensitivity analysis). These two steps use the objective data collected from the three assessment groups (e.g., foreman, supervisors and peers, and crew members).

The validation and sensitivity analysis are two different processes but similar in the context of using objective data to test the model. While the validation of the model involves the base case model, the sensitivity analysis includes changes such as membership functions shapes, implication and aggregation methods, and defuzzification processes.

The crisp output obtained for each data point is compared to the actual output of the existing data. The percentage error is then calculated using the following formula:

$$\text{Percentage of Error} = \frac{[\textit{Predicted Output} - \textit{Actual Output}]}{\textit{Actual Output}} \times 100 \qquad [6.1]$$

where,

Predicted Output: Value generated by the fuzzy logic model after deffuzification.

Actual Output: Real value given by experts opinion, company data or calculated using statistical method.

For the rule base to be considered adequate, the percentage error for each data point must be less than or equal to 33%. Therefore, a numerical match is achieved if the percentage error is not more than 33%. If the linguistic term of the defuzzification output is the same as that of the actual output, then the data point has a linguistic match. Also, for the model to be considered successful, the percentage of numerical or linguistic matches over the total number of data points should be greater than or equal to 50% (Sun, 2001). It is necessary to create a criteria of acceptance for each fuzzy logic model because of the uniqueness of each model; after the sensitivity analysis the design of each model will be complete presenting unique characteristic such as membership functions shapes, aggregation and implication methods, and defuzzification. The criteria of acceptance are also considered distinctive for each fuzzy logic model. For the foreman's performance evaluation and prediction the author considered a distinct rationale than Sun (2001), because of the particular characteristics of the fuzzy logic model and the limited data available to design and validate it the author considered the necessity to be stricter in the percentage difference between the statistical and fuzzy logic model.

In the case of predicting and evaluating performance the percentage difference between the statistical and fuzzy logic method must be lower than 7.1%. This mean, if the value obtained using the statistical method is 5.0, the value using the fuzzy logic model must be in between 4.35 and 5.35. The 7-point semantic differential scale was chosen to evaluate each task, each point represent the assessment given by the participants in the evaluation process. The author proposes that the values obtained using the fuzzy logic model should not vary more than +/- 0.5 of an evaluation point calculated using the statistical model. However, each point in the scale would have a different percentage difference from this evaluation point, as shown in Table 6-1. For example, if the value obtained using the statistical method is 5.0, and the value using the fuzzy logic model is 6.5, this means that the percentage of error is 30%. A 5.0 in the scale represents a "slightly high performance", but 6.5 represents a "high performance" according to the linguistic scale used to evaluate the foreman's performance. In conclusion, the author decided not allow the fuzzy logic output to overrule the value obtained with the statistical method by using a 7.1 % maximum difference between the models as criteria.

The maximum percentages difference allow by the criteria are calculated using the following formula:

$$\text{Maximum \% Difference} = \left| \frac{[\textit{Higher or Lower Value} - \textit{Scale Point}]}{\textit{Scale Point}} \right| \times 100 \quad [6.2]$$

Where,

Higher orLower values: are the maximum and minimum values allow by using the fuzzy logic model (output) to not overrule the values given by the group assessments.

Scale Point: are the values in the 7-point scale used in the statistical model.

Table 6-1: Percentage Difference Allowed by the Criteria for Each Scale Point

| Scale Point (Statistical Model) | Higher/Lower Value Fuzzy Logic Model Output | | Maximum Percentage Difference Allow by the Criteria (%) |
|---|---|---|---|
| 1 | Higher Value | 1.49 | 49.0 |
| 2 | Lower Value | 1.50 | 25.0 |
| | Higher Value | 2.49 | 24.5 |
| 3 | Lower Value | 2.50 | 16.7 |
| | Higher Value | 3.49 | 16.3 |
| 4 | Lower Value | 3.50 | 12.5 |
| | Higher Value | 4.49 | 12.3 |
| 5 | Lower Value | 4.50 | 10.0 |
| | Higher Value | 5.49 | 9.51 |
| 6 | Lower Value | 5.50 | 8.3 |
| | Higher Value | 6.49 | 8.2 |
| 7 | Lower Value | 6.50 | 7.1 |

As table 6-1 shows the maximum percentage difference between the statistical and fuzzy logic model allows is 7.1% for all the points in the scale to maintain the established criteria. Some points in the scale such 1 allows a 49% difference between models, however, the 49% difference apply to the 7 point in the scale would allow values in the range of 3.57 to 7.0, which clearly would be beyond the +/- 0.5 criteria.

In this research, the author compared the results obtained in the fuzzy logic model with the results of the statistical model designed by Fayek and Poveda (2008). Since both models are different approaches to measure the foreman's performance, the author has modified the formula to measure not percentage of error but percentage difference between the two approaches (e.g., fuzzy logic model, and statistical model). The predicted value in equation 6.1 was replaced by the value obtained from fuzzy logic model after deffuzification, and the actual output was replaced by the value obtained using the statistical model (Fayek and Poveda. 2008). The formula used to measure the percentage difference was:

$$\text{Percentage difference: } \frac{[\mathit{Fuzzy\ Logic\ Output} - \mathit{Statistical\ Output}]}{\mathit{Statistical\ Output}} \times 100 \qquad [6.3]$$

where,

Fuzzy Logic Output: Value using the fuzzy logic model

Statistical Output: Value using the statistical method designed by Fayek and Poveda. (2008).

## 6.2 Model Validation

The model validation involves applying the objective data collected from the three group assessments. To validate the model, 17 sets of data were available, each set of data represents one foreman evaluation by the group assessments (e.g., foreman, supervisors and peers, and crew members). The characteristics for the base case model were:

- **Membership functions**: Combination of triangular and trapezoidal shapes
- **Defuzzification method**: CoM (center of maximum or mean of maxima). The CoM first determines the most typical value for each linguistic term for an output linguistic variable, and then computes the crisp value as the best compromise for the typical values and respective

degrees of membership. The most typical value of each linguistic term is the maximum of the respective membership function. If the membership function has a maximizing interval, the median of that interval is taken.

- **Implication**: Min, and **Aggregation**: Max
  The implication method defines rules by linking combinations of input variables to output variables, also combine membership values of all antecedents (all input variables), the most common operators are AND (min) and OR (max). Usually AND is used for independent input variables and OR for correlated input variables. The aggregation combined all the output from each rule into a single fuzzy set. The aggregation occurs once for each output variable, and it results in one fuzzy set for each output variable. The most common aggregation method are max; takes maximum value of each output set (from each rule) for a given output variable, sum; sum each rule's output set, and probor; algebraic sum of each rule's output set occurs.

The output of each test was a crisp value after defuzzification. Whether the model is successful or not depends on how close the defuzzified crisp value is to the actual value calculated using the statistical method.

The overall results of the base case testing are shown in Table 6-1 (shows the percentage difference between the statistical and the fuzzy logic model results according to Equation 6.2). The values for the outputs were considered successful match because the average percentage difference for each category was less than 7.1% and the overall foreman's performance evaluation was even less than 5%. Although the percentage differences obtained in the base case were considered acceptable, the sensitivity analysis was needed to verify if the accuracy of the model could be improved.

For each foreman participant in this research, a set of data was collected. These set of data consist of assessments from 3 different groups (e.g., foreman, supervisors and peers, crew members). These values were re-grouped and processed (see Chapter 4) to conform the inputs of the model. Each foreman obtained a performance evaluation in each of the categories (e.g., safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration) and in the overall performance (final output). The values obtained for each foreman were averaged to calculate the final percentage difference in each category and final output (e.g. overall performance). Details of how the values shown in Table 6-2 were calculated are attached in Appendix G.

Table 6-2: Overall Testing Results for Base Case – Validation

| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 6.40 % |
| QA/QC | 8.17 % |
| Leadership and Supervision | 5.53 % |
| Employee Relations | 7.90 % |
| Planning and Scheduling | 8.15 % |
| Administration | 6.34 % |
| Overall Foreman's Skill Level | 4.68 % |

## 6.3 Model Sensitivity Analysis

To determine which operators in the fuzzy logic model affect the outputs of the model to the greatest degree, it is necessary to perform a sensitivity analysis. These results may provide information helping to improve the accuracy of the model. In this research, the sensitivity analysis was conducted by changing three different operators in the model: membership functions shapes, defuzzification methods, and implication and aggregation methods.

### 6.3.1 Sensitivity Analysis Based on Membership Functions Shapes

Many different shapes of membership functions are proposed in scientific literature. However, most practical implementations only use so-called "Standard Membership Functions" (Standard-MBF). Four different types of Standard-MBFs exist: Z-type, Lambda-type (lambda), Pi-Type (pi), and S-type. Figure 6-1 shows these four types. Standard-MBFs are also normalized, that is, their maximum is always $\mu=1$, their minimum =0.

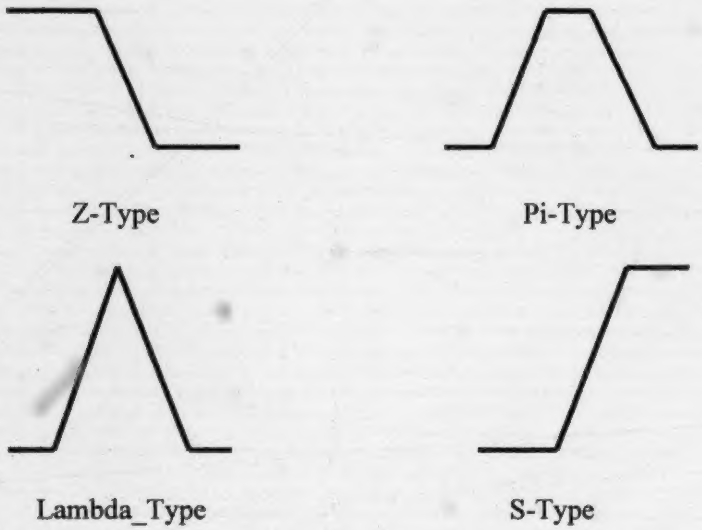


Figure 6-1: Membership Functions Shapes

The sensitivity analysis based on membership functions evaluated the effect of changing the membership function shapes used for the input and output variables. In this case, four different scenarios were evaluated: the base case combines trapezoidal and triangular membership functions shapes, sensitivity analysis No 1 involves only triangular membership functions shapes (e.g. lambda type), sensitivity analysis No 2 works only with trapezoidal membership functions shapes (e.g. Pi type), and sensitivity analysis No 3 has only S-shape membership functions (e.g. Z and S type).

### 6.3.1.1 Base Case for MBF

The base case was used in the validation of the fuzzy logic model and explained in Section 6.2 of the thesis. A combination of trapezoidal and triangular membership functions shapes were used in this process and the results are shown in Table 6-1.

Figure 6-2 shows a sample of the membership functions used in the case base of the fuzzy logic model.

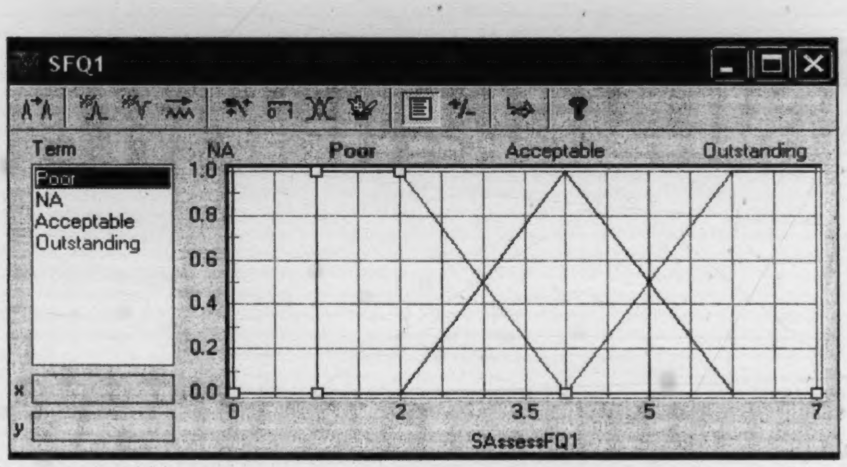
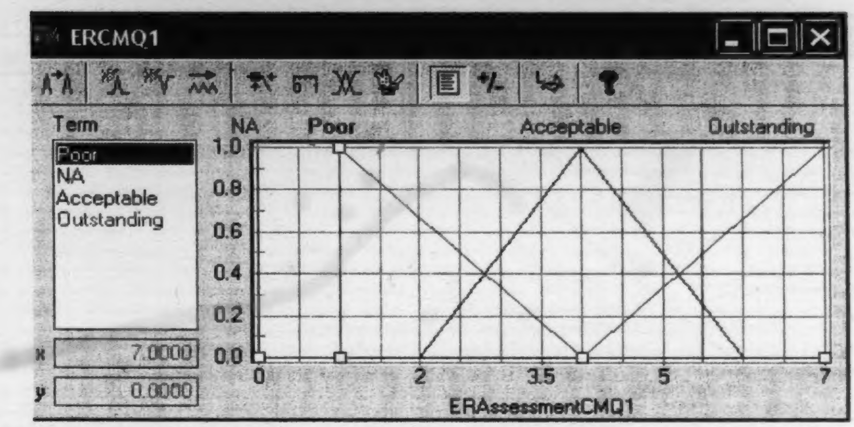

SFQ1
Term
Poor
NA
Acceptable
Outstanding
x
y
NA
Poor
Acceptable
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
SAssessFQ1

Figure 6-2: Membership Functions Used in Case Base

### 6.3.1.2 MBF With Triangular Shapes – Sensitivity Analysis I

Using only triangular membership function shapes was the first change made in the fuzzy logic model. Input and output variables used the same triangular shapes as in Figure 6-3. The other characteristics of the model (e.g., defuzzification method, implication method, and aggregation method) were kept the same as the base case. The results of this sensitivity analysis are shown in Table 6-2. Appendix H shows more details of how the values shown in table 6-3 were calculated.


ERCMQ1
Term
Poor
NA
Acceptable
Outstanding
NA
Poor
Acceptable
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
ERAssessmentCMQ1

x 7.0000
y 0.0000

Figure 6-3: Membership Functions Used Sensitivity Analysis I

Table 6-3: Sensitivity Analysis I Results

| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 9.77 % |
| QA/QC | 11.98 % |
| Leadership and Supervision | 7.50 % |
| Employee Relations | 8.71 % |
| Planning and Scheduling | 10.41 % |
| Administration | 8.12 % |
| Overall Foreman's Skill Level | 6.15 % |

According to sensitivity analysis I, using only triangular shapes for the membership functions affects the base case model by increasing the percentage difference (i.e. error) between the statistical and fuzzy logic model. Although the accuracy of the model is affected negatively, the overall foreman's skill level evaluation still lower than 7%, and categories such as safety, leadership and supervision, employee relations, administration, are slightly over the criteria.

### 6.3.1.3 Trapezoidal Shapes – Sensitivity Analysis II

The second sensitivity analysis involves only membership functions with trapezoidal shapes. An example of these membership functions are shown in Figure 6-4. The results of this analysis are presented in Table 6-3. The use of membership function with trapezoidal shape was the only difference with the base case. Details of the calculations show in Table 6-4 can be found in Appendix I.

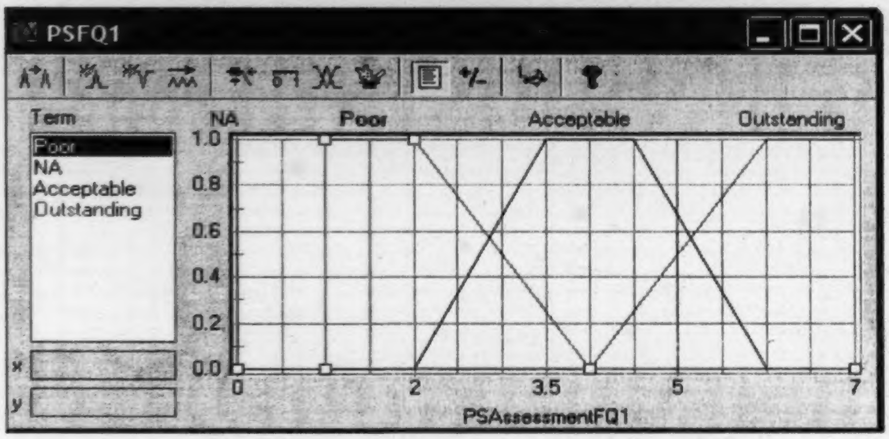

PSFQ1
Term
Poor
NA
Acceptable
Outstanding
x
y
NA
Poor
Acceptable
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
PSAssessmentFQ1

Figure 6-4: Membership Functions Used Sensitivity Analysis II

Table 6-4: Sensitivity Analysis II Results

| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 6.19 % |
| QA/QC | 8.05 % |
| Leadership and Supervision | 5.44 % |
| Employee Relations | 7.37 % |
| Planning and Scheduling | 7.00 % |
| Administration | 5.99 % |
| Overall Foreman's Skill Level | 4.52 % |

The sensitivity analysis shows that using trapezoidal shapes for the membership functions impact the fuzzy logic model in a positive manner. The percentage of difference between the two models presented a slight improvement in each category. Although the percentage of improvement is less than 3% it can be concluded that the accuracy of the model has been improved.

#### 6.3.1.4 S-Shapes – Sensitivity Analysis III

The last sensitivity analysis involved only membership functions with S-shapes as Figure 6-5 shows. The results of this analysis are presented in Table 6-5. The other characteristics of the model such as defuzzification method, implication method, and aggregation method still the same as the base case. Details of how the values shown in Table 6-4 were calculated are attached in Appendix J.

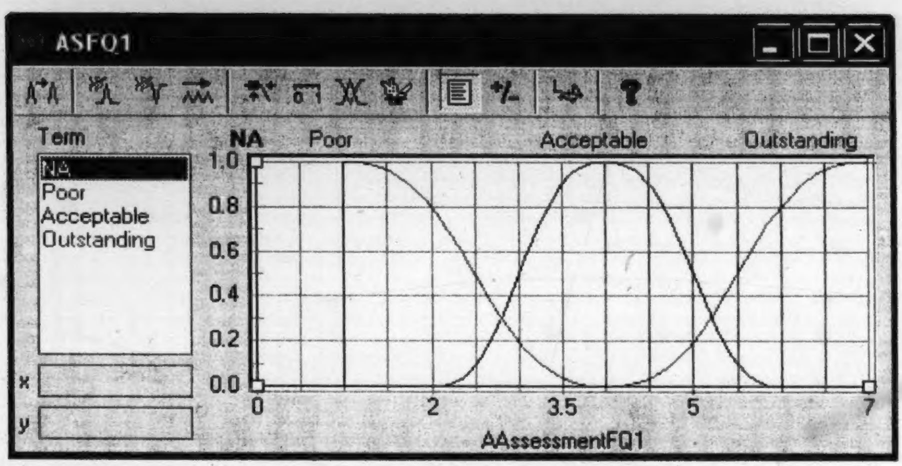

ASFQ1
Term
NA
Poor
Acceptable
Outstanding
x
y
NA
Poor
Acceptable
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
AAssessmentFQ1

Figure 6-5: Membership Functions Used Sensitivity Analysis III

Table 6-5: Sensitivity Analysis III Results

| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 13.06 % |
| QA/QC | 15.54 % |
| Leadership and Supervision | 13.05 % |
| Employee Relations | 15.92 % |
| Planning and Scheduling | 15.78 % |
| Administration | 12.81 % |
| Overall Foreman's Skill Level | 12.04 % |

Based on the results obtained in the sensitivity analysis III it can be concluded that using S-shaped membership functions impact the accuracy of the model negatively. The percentage of difference between models (e.g., statistical and fuzzy logic model) presented an average increase of more than 100% with respect to the base case.

### 6.3.2 Sensitivity Analysis Based on Implication/Aggregation Method

The last set of changes in the sensitivity analysis of the fuzzy logic model involved the implication and aggregation methods. The "min" and "max" were used for implication methods, and "max" and "BSum" were used for aggregation methods. In this stage of the sensitivity analysis the other characteristics of the model (e.g., membership function shapes, defuzzification method) were kept as the case base was presented (combination of triangular and trapezoidal membership shapes, and CoM defuzzification method).

#### 6.3.2.1 Base Case for Implication and Aggregation

In the base case "min" was used as implication method and "max" as aggregation method. In Fuzzy-Tech the aggregation method "min" corresponds with the linguistic "AND", and the implication method "max" selects the maximum firing degree of all rules matching to the term. The results of the case base are discussed in Section 6.2 and the presented in table 6.1 of this thesis.

The operators used in the implication process can be represented as:

AND: $\mu_{IF} = \min_i (\mu_i)$ [6.4]

OR: $\mu_{IF} = \max_i (\mu_i)$ [6.5]

Min-Max: $\mu_{IF} = (1 - \lambda) * \min_i (\mu_i) + (\lambda) * \max_i (\mu_i)$ [6.6]

If, $\lambda = 0$ then, operator = Min (AND)

$\lambda = 1$ then, operator= Max (OR)

Min-Ave: $\mu_{IF} = (1 - \lambda) * \min_i (\mu_i) + (\lambda) * \sum_{i=0}^{n} \mu i / n$ [6.7]

If, $\lambda = 0$ then, operator = AVG (Average)

GAMMA : $\mu_{IF} = ( \prod_{i=0}^{n} (\mu i))^{1-\gamma} * ( 1 - \prod_{i=0}^{n} (\mu i))^{\gamma} \quad )$ [6.8]

If, $\gamma = 0$ then, operator =PROD (Product)

The operators used in the aggregation process can be represented as:

MAX result aggregation: $\mu_{RESULT} = \max_i (\mu_{THEN,RLUE\ i})$ [6.9]

BSUM result aggregation: $\mu_{RESULT} = \min(1, \sum(\mu THEN, RLUE\ i))$ [6.10]

#### 6.3.2.2 Implication Using "MAX" Operator and Aggregation Using "MAX" Operator – Sensitivity Analysis IV

Changing the characteristics of the case base for "max" as implication method ("max" corresponds with the linguistic "OR") and keeping "max" as aggregation method the results changed drastically as Table 6-6 shows. The complete calculation to support these results is presented in Appendix K.

Table 6-6: Sensitivity Analysis IV Results

| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 35.53 % |
| QA/QC | 40.45 % |
| Leadership and Supervision | 37.27 % |
| Employee Relations | 30.76 % |
| Planning and Scheduling | 35.10 % |
| Administration | 44.63 % |
| Overall Foreman's Skill Level | 43.37 % |

The results of changing the implication method to "max" (OR) demonstrated that it can impact the accuracy of the model in a negative manner. The percentage difference between the models (e.g., statistical and fuzzy logic model) in each category and the final out (e.g., overall performance) increased significantly. Not only the percentages difference increased more than 500% but they are also out of the range of acceptance for the model according to the criteria pre-established by the author.

#### 6.3.2.3 Implication Using "MIN" Operator and Aggregation Using "BSUM" Operator – Sensitivity Analysis V

In this case, "min" was used as implication method (corresponds with the linguistic "AND") and "BSum" which uses a bounded sum ("BSum" all firing degrees are summed by using a bound of 1.0) was used as aggregation method. The results are presented in Table 6-7 and the complete analysis is attached in Appendix L.

Table 6-7: Sensitivity Analysis V Results

| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 5.36 % |
| QA/QC | 7.36 % |
| Leadership and Supervision | 5.42 % |
| Employee Relations | 5.39 % |
| Planning and Scheduling | 6.97 % |
| Administration | 3.89 % |
| Overall Foreman's Skill Level | 4.51 % |

In this case, the accuracy of the model improved significantly in the category of administration; the other categories improved their percentage difference but slightly. Furthermore, it can be concluded that this aggregation method does impact positively the accuracy of the model and offer a better option for aggregation.

### 6.3.3 Sensitivity Analysis Based on Defuzzification Methods

The second set of changes in the sensitivity analysis of the fuzzy logic model involved the defuzzification methods. In this case, four different defuzzification methods were used: CoM, MoM, Fast CoA, and Hyper CoM. The case base involved the CoM defuzzification methods, for that instance the sensitivity analysis was done using the other three methods that Fuzzy-Tech (INFORM GmbH., 2008) offers for its users. The rest of the characteristics of the model were kept as the case base indicates: combination of triangular and trapezoidal membership function shapes, Min as implication method, and Max as aggregation method.

#### 6.3.3.1 Deffuzification Method Selection and Comparison (Most common applications)

The continuity property is important for most closed-loop control applications, if the output of a fuzzy logic system directly controls a variable of the process, jumps in the output variable of a fuzzy logic controller can cause instabilities and oscillations. Hence, most closed-loop control application uses CoM defuzzification. Only when the output of the fuzzy logic system proceeds to an integrator first, MoM is a possible alternative. In this case, the integrator keeps the control variable continuos.

Pattern recognition applications mostly use MoM defuzzification. If the desire is to identify objects by classification of a sensor signal, the interest is in the most plausible result. Some applications even do not use any defuzzification at all. The vector of membership degree for the output linguistic variable is the result of the classification as it gives the similarity of the signal to the objects.

In decision support systems, the choice of defuzzification method depends on the context of the decision, use CoM for quantitative decisions, such as budget allocation or project prioritization, Use MoM for qualitative decisions, such as credit card fraud detection or credit worthiness evaluation.

In practical applications, the only difference between defuzzification methods is, whether they deliver the best compromise (CoM, CoA, and CoG) or the most plausible result (MoM, LoM, and RoM).

Within these groups, no relevant differences exist that cannot be equalized by modifying membership functions or rules. Complete membership function shapes do not deliver better results for output variables. CoM and MoM defuzzification methods only use the maximum of the membership functions anyway.

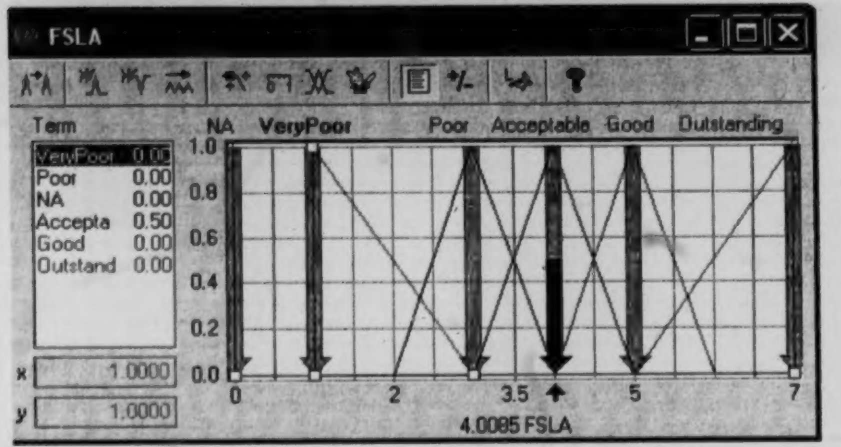
In closed-loop control, only use CoM defuzzication. Exceptions are, if the output of the fuzzy logic system proceeds to an integrator. The wide spread use of CoA/CoG defuzzification has historical reasons, Depending on the overlap and different areas of the membership functions, CoA/CoG can deliver implausible results. Use CoM instead.

Some applications use CoA defuzzification with singleton membership functions, this is completely the same as CoM defuzzification with any membership type.

While the CoM and CoA defuzzification methods result in the "best compromise solution", MoM resulted in the "most plausible solution". In control applications, CoM is most commonly used because the output value represents the best compromise of all inferred results. MoM is often used in pattern recognition and classification applications as a plausible solution is here most appropriate. Scientific literature has suggested many other defuzzification strategies, which until now have rarely been used in industrial applications.

### 6.3.3.2 Base Case for Defuzzification

Because more than one output term can be evaluated as valid, the defuzzification method must compromise between the different results. The Center of Maximum Method (CoM) does this by computing a crisp output as a weighted average of the term membership maxima, weighted by the inference results. Figure 6-6 illustrates CoM defuzzification for the final output (e.g., foreman's skill evaluation). The locations of the individual term membership maxima are indicated by the grey arrows, and the inference result is shown by the height of the black bar in the arrows. The base case was discussed in Section 6.2 of the thesis, and it involves the use of the CoM defuzzification method.


FSLA
Term
NA
VeryPoor
Poor
Acceptable
Good
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
4.0085 FSLA

| | |
|---|---|
| VeryPoor | 0.00 |
| Poor | 0.00 |
| NA | 0.00 |
| Accepta | 0.50 |
| Good | 0.00 |
| Outstand | 0.00 |

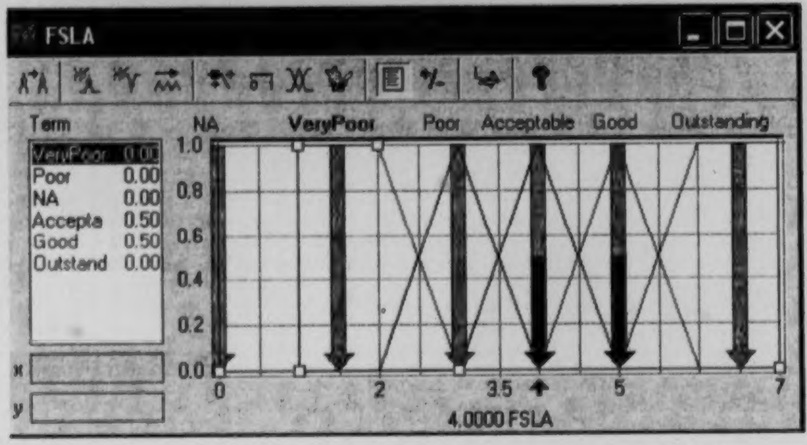
x 1.0000

y 1.0000

Figure 6-6: Defuzzification With Center of Maximum

6.3.3.3 MoM Defuzzification Method – Sensitivity Analysis VI

The Mean-of-Maximum Method (MoM) takes the average value of all elements whose membership value is equivalent to the maximum value. It only takes into account the elements with maximum membership instead of all elements like the CoA method. Fuzzy-Tech (INFORM GmbH., 2008) computes a system output only for the term with the highest resulting degree of support. If the maximum is not unique (like in a Pi-shaped MBF), the mean of the maximizing interval is computed. Figure 6-7 illustrates the MoM defuzzification procedure for the final output (e.g., foreman's skill evaluation).


FSLA
Term
NA
VeryPoor
Poor
Acceptable
Good
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
x
y
4.0000 FSLA

| | |
|---|---|
| VeryPoor | 0.00 |
| Poor | 0.00 |
| NA | 0.00 |
| Accepta | 0.50 |
| Good | 0.50 |
| Outstand | 0.00 |

Figure 6-7: Mean of Maximum Defuzzification Method

The complete results are shown in Table 6-8, and details of the calculations are included in Appendix M.

Table 6-8: Sensitivity Analysis VI Results

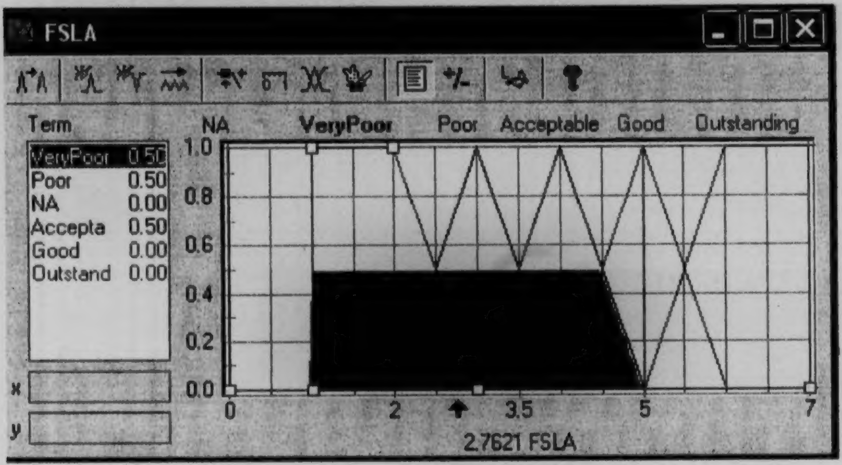
| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 17.98 % |
| QA/QC | 18.73 % |
| Leadership and Supervision | 20.41 % |
| Employee Relations | 21.06 % |
| Planning and Scheduling | 18.35 % |
| Administration | 22.21 % |
| Overall Foreman's Skill Level | 20.16 % |

The sensitivity analysis shows that using the Mean of Maxima for defuzzification method impacts the model accuracy in a negative manner. The percentage of difference between the two models increases between 250% to 500%.

#### 6.3.3.4 Fast CoA Defuzzification Method – Sensitivity Analysis VII

Center-of-Area (CoA) is the most frequently used defuzzification method in fuzzy systems. With singleton membership functions, CoA and CoM defuzzification are identical. Most CoA implementations are only approximations since they neglect overlapping and can be represented with the CoM defuzzification method.

The CoA defuzzification supported by FuzzyTech (INFORM GmbH., 2008) is not an approximation as it uses numerical integration for the computation of the areas. Although specification of the number of iterations used for numerical integration is possible, the real CoA defuzzification is much slower than an approximated CoA defuzzification, i.e., COM, because it is computed during runtime. Figure 6-8 illustrates the CoA defuzzification process for the final output (e.g., foreman's skill evaluation).


FSLA
NA
VeryPoor
Poor
Acceptable
Good
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
x
y

| Term | |
|---|---|
| VeryPoor | 0.50 |
| Poor | 0.50 |
| NA | 0.00 |
| Accepta | 0.50 |
| Good | 0.00 |
| Outstand | 0.00 |

2.7621 FSLA

Figure 6-8: Defuzzification With Center of Area

The Fast-CoA that is used in most software tools and a fuzzy logic processor is equal to a weighted CoM defuzzification. The results of applying the Fast CoA defuzzification method are shown in Table 6-9, and details of these calculations are included in Appendix N.

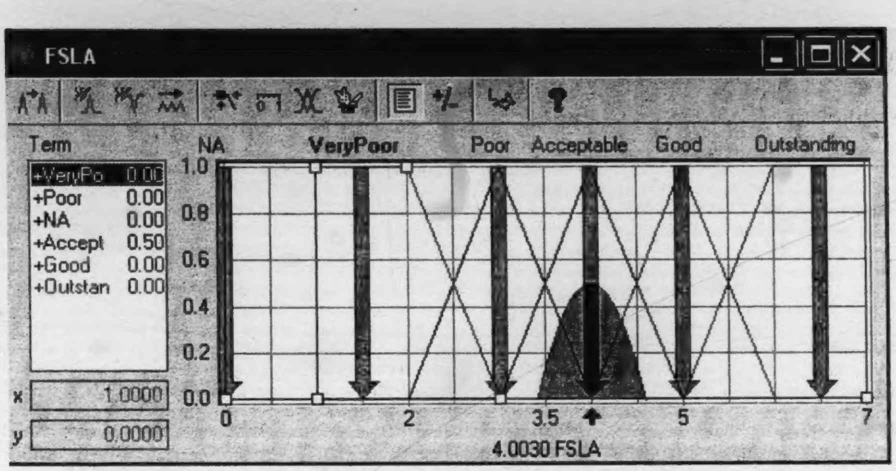
Table 6-9: Sensitivity Analysis VII Results

| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 3.64 % |
| QA/QC | 5.06 % |
| Leadership and Supervision | 5.15 % |
| Employee Relations | 5.12 % |
| Planning and Scheduling | 6.43 % |
| Administration | 3.69 % |
| Overall Foreman's Skill Level | 4.27 % |

According to sensitivity analysis VII, using for defuzzification the center of area method affects the base case model by decreasing the percentage difference between the statistical and fuzzy logic model. The best results obtained in all sensitivity analysis (8 in total) demonstrated to improve the accuracy of the model by 27.85 % as Table 6-12 shows.

#### 6.3.3.5 Hyper CoM Defuzzification – Sensitivity Analysis VIII

The last defuzzification method used in the sensitivity analysis was the Hyper CoM. It is not commonly use in fuzzy logic model, however, in many applications, not only positive experience in the form of recommendations is of importance, but also negative experience in the form of warnings and prohibitions. It has to be said that it is impossible to switch from Hyper CoM into another defuzzification method as long as a variable has negative terms. HyperCoM is a defuzzification method that takes both positive and negative experience into consideration (e.g. in the form of recommendations and warnings). A hyperdefuzzification strategy weights these recommendations and warnings against each other and computes a membership function, from which HyperCoM then computes the optimum based output value



FSLA
NA
VeryPoor
Poor
Acceptable
Good
Outstanding
1.0
0.8
0.6
0.4
0.2
0.0
0
2
3.5
5
7
4.0030 FSLA

| Term | |
|---|---|
| +VeryPo | 0.00 |
| +Poor | 0.00 |
| +NA | 0.00 |
| +Accept | 0.50 |
| +Good | 0.00 |
| +Outstan | 0.00 |

x 1.0000

y 0.0000

Figure 6-9: Defuzzification With Hyper CoM

Table 6-10 presents the complete results of applying Hyper CoM as the defuzzification method. Appendix O includes the details of how the calculations were made.

Table 6-10: Sensitivity Analysis VIII Results

| Category | Percentage Difference (Equation 6.2) |
|---|---|
| Safety | 6.31 % |
| QA/QC | 8.22 % |
| Leadership and Supervision | 5.49 % |
| Employee Relations | 7.87 % |
| Planning and Scheduling | 8.20 % |
| Administration | 6.46 % |
| Overall Foreman's Skill Level | 4.42 % |

The sensitivity analysis VIII, which uses the HyperCoM defuzzification method, presented results similar to the base case. Although the accuracy of the model improved, the percentage of improvement is less than 1%.

### 6.4 Conclusions From Sensitivity Analysis

The comparison results for the sensitivity analysis are shown in Table 6-11. From this table the author concluded that sensitivity analysis V presented the best results since the percentage difference between the statistical and fuzzy logic model is lower than the results obtained in the base case, which represents an increase in the accuracy of the model. The characteristics of the model in sensitivity analysis VII were:

- Membership functions shape: Combination of triangular and trapezoidal as Figure 6-2 shows.
- Defuzzification method: Fast CoA
- Implication Method: Min (corresponds with the linguistic "AND")
- Aggregation Method: Max ("max" selects the maximum firing degree of all rules matching to the term)

Table 6-11 also shows that in sensitivity analysis IV the model presents a low level of accuracy, it may indicate that the implication method considerably affects the results of the model. The characteristics of the model in sensitivity analysis IV are explained in Section 6.3.3.2.

The other two sensitivity analyze that presented low accuracy in the model were sensitivity analysis III and VI. In sensitivity analysis III membership functions with S-shapes were used, and in sensitivity analysis VI the defuzzification method used was MoM.

Table 6-11: Sensitivity Analysis Comparison Results

| | Safety | QA/QC | Leadership and Supervision | Employee Relations | Planning and Scheduling | Administration | Overall Performance |
|---|---|---|---|---|---|---|---|
| Base Case | 6.40 | 8.17 | 5.53 | 7.90 | 8.15 | 6.34 | 4.68 |
| Sensitivity I | 9.77 | 11.98 | 7.50 | 8.71 | 10.41 | 8.12 | 6.15 |
| Sensitivity II | 6.19 | 8.05 | 5.44 | 7.37 | 7.00 | 5.99 | 4.52 |
| Sensitivity III | 13.06 | 15.54 | 13.05 | 15.92 | 15.78 | 12.81 | 12.04 |
| Sensitivity IV | 35.53 | 40.45 | 37.27 | 30.76 | 35.10 | 44.63 | 43.37 |
| Sensitivity V | 5.36 | 7.36 | 5.42 | 5.39 | 6.97 | 3.89 | 4.51 |
| Sensitivity VI | 17.98 | 18.73 | 20.41 | 21.06 | 18.35 | 22.21 | 20.16 |
| Sensitivity VII | **3.64** | **5.06** | **5.15** | **5.12** | **6.43** | **3.69** | **4.27** |
| Sensitivity VIII | 6.31 | 8.22 | 5.49 | 7.87 | 8.20 | 6.46 | 4.42 |

To understand the results obtained in sensitivity analysis VII discussed in Section 6.3.2.3, which presented the best result, Table 6-12 presents a comparison between the results of sensitivity analysis VII and hypothetical values using the statistical model. The range of values expected using the fuzzy logic model are also presented. The range of values expected using the fuzzy logic model is calculated by adding or subtracting the percentage difference between models in sensitivity analysis VII. For example, if using the statistical model the foreman's performance evaluation in the category of safety is 5.0, the range of value expected using the fuzzy logic model would be calculated as:

$$5 - (5 * 0.0364) = 4.82 \qquad [6.11]$$

$$5 + (5 * 0.0364) = 5.18 \qquad [6.12]$$

Table 6-12: Range of Values Expected Using Fuzzy Logic Model - Sample

| Category | % Difference Between Models Using Sensitivity Analysis VII | Hypothetical Results Using Statistical Model | Range of Values Expected Using Fuzzy Logic Model |
|---|---|---|---|
| Safety | 3.64 | 5.00 | 4.82 – 5.18 |
| QA/QC | 5.06 | 5.00 | 4.75 – 5.25 |
| Leadership and Supervision | 5.15 | 5.00 | 4.74 – 5.26 |
| Employee Relation | 5.12 | 5.00 | 4.74 – 5.26 |
| Planning and Scheduling | 6.43 | 5.00 | 4.68 – 5.32 |
| Administration | 3.69 | 5.00 | 4.82 -5.16 |
| Overall Foreman's Skill Level | 4.27 | 5.00 | 4.79 – 5.22 |

The author considered that sensitivity analysis VII contains the best characteristics for the fuzzy logic model; Table 6-13 shows the percentage of improvement. This percentage of improvement is calculated making a comparison between the base case and the fuzzy logic model in sensitivity analysis VII. In general, the results improved by 27.85 %.

Table 6-13: Fuzzy Logic Model Percentage of Improvement

| Category | % Difference Base Case | % Difference Sensitivity Analysis VII (Best Results) | Percentage of Improvement of Results |
|---|---|---|---|
| Safety | 6.40 | 3.64 | 43.13 |
| QA/QC | 8.17 | 5.06 | 38.07 |
| Leadership and Supervision | 5.53 | 5.15 | 6.87 |
| Employee Relations | 7.90 | 5.12 | 35.19 |
| Planning and Scheduling | 8.15 | 6.43 | 21.10 |
| Administration | 6.34 | 3.69 | 41.80 |
| Overall Foreman's Skills Level | 4.68 | 4.27 | 8.76 |
| Fuzzy Logic Model Overall Improvement | | | 27.85 |

## 6.7 Summary

In this chapter, the complete results of the validation and sensitivity analysis were presented. The constructed model was tested using actual data in both processes (e.g. validation process, and sensitivity analysis). The sensitivity analysis provided insight into methods to improve the accuracy of the model. The author considers the model a success since the percentage difference between models (e.g., statistical and fuzzy logic model) is considerably low as Tables 6-10 and 6-12 show. The following chapter will discuss what future work can be done to improve the fuzzy logic model and what other areas of research can be explored based on this research.

# CHAPTER 7 CONCLUSIONS AND FUTURE RESEARCH

## 7.1 Conclusions

The objective of this research was to develop a model for use in predicting and evaluating the performance of construction trades foremen using fuzzy set theory and fuzzy logic techniques. This objective was achieved by identifying the factors that affect the foreman's performance ( Fayek and Poveda, 2008), generating membership functions for each of the factors, building a comprehensive rule base for a fuzzy expert system, and finally constructing and testing the fuzzy logic model using a software environment (e.g., Fuzzy-Tech).

The first phase of the research was to identify a thorough list of factors that would affect the foreman's performance. Based on the job description for industrial construction trades foremen developed by the Construction Owners Association of Alberta (COAA) and an extensive literature review related to foreman's performance, the factors were identified. Following this job description the factors were divided in six areas of responsibility (e.g. categories): safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration. The preliminary model was designed based on the factors identified in each category and the structure of the group assessments involved in the performance evaluation (e.g., foreman, supervisor and peers, and crew members).

In the next phase, the data collection process was designed. Three questionnaires were developed to collect information related to foreman's skills, training, knowledge, education level, work experience, and attitude, which are intrinsic in the six categories of responsibility. Also, the methodology to collect the data was developed: rating scale, identification of group assessment, and administration of questionnaires. Seventeen sets of responses were collected based on the self-completed questionnaires. Each set of data consisted of responses from the three group assessments (e.g., foreman him/herself, supervisors and peers, and crew members). The data collected was processed for developing and testing the fuzzy logic model.

The third phase of the study focused on the model's simplification. Due the extensive number of factors involved in the foreman's performance evaluation, this made the model complex; it was difficult to generate rules to implement them in computerized form. A series of criteria were selected to re-group the factors and to reduce the input variables in the model. These series of criteria not only simplified the model, but also opened an extensive area for future research in performance evaluation; identification of factors that impact performance, group assessments selection (which group brings more accurate assessment in the evaluation process), correlation between group assessments, weight of group assessments in the evaluation process, and weight between categories of evaluation; these areas of research should be explored to bring new elements into the overall performance evaluation area.

The fourth phase of the project focuses on the development of the fuzzy expert system. The fuzzy expert system consists of membership functions, a fuzzy rule base, a fuzzy inference system (implication and aggregation methods), and a defuzzification module. At this stage in the process, the generation of membership functions was based on objective values. The development of membership functions was done using logical reasoning and making use of the limited data collected in previous stages of the project. The next step focused on developing the fuzzy If-Then rules. The rules were developed using the auto-generation of rules in Fuzzy-Tech and applying the logic between the input variables (factors) and the expected output variables. The model was tested with the actual data collected from the survey (validation and sensitivity analysis). The results obtained were considered acceptable, especially because the percentage difference between the statistical and fuzzy logic model were less than 7% and even less than 5% in some cases. The author considers that the series of criteria employed in the model to re-group the factors that affect the foreman's performance were accurate and demonstrated the correctness of the relationship between factors, input variables (chapter 3, tables 3-1 to 3-6) and categories (safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration), however, further research in this area is suggested.

In the last stage of this study, a validation and sensitivity analysis of the fuzzy expert system were conducted, by changing several parameters. The membership functions shapes, the fuzzy inference operations (implication and aggregation methods), and defuzzification methods were tested to increased the accuracy of the model. The results indicate that the model is sensitive to each one of the changes made in the model, as Chapter 6 describes). Changing the membership functions indicates that the model is sensitive to each parameter to some extent, the characteristics of the model with best results are:

- Membership functions shapes: Combination of triangular and trapezoidal
- Implication: Min
- Aggregation: Max
- Defuzzification Method: Fast CoA

The combination of triangular and trapezoidal membership function are distributed as follow:

- Inputs and Intermediate outputs/inputs
  Poor: Trapezoidal
  Acceptable: Triangular
  Outstanding: Trapezoidal
- Final Output (Overall performance evaluation)
  Very Poor: Trapezoidal
  Poor: Triangular
  Acceptable: Triangular
  Good: Triangular
  Outstanding: Trapezoidal

The parameters the model is most sensitive were the S-shape membership functions (using s-shape for all memberships in the model), implication method of MAX (linguistic "OR"), and MoM defuzzification method. Any of these three parameters decreased the accuracy of the model by a considerable margin.

This study demonstrate the benefits of using the fuzzy set theory to model prediction and evaluation of performance, in which subjective evaluations are given by different group assessments. The fuzzy expert system developed shows a good reliability of the input variables in each area of responsibility involved in evaluating the foreman's performance. The use of linguistic values for decision making is a realistic and desirable tool for project management.

## 7.2 Uses of the Fuzzy Logic Model

This thesis presents a practical methodology to predict and evaluate the performance of construction trades foremen, and identifies the factors that directly and/or indirectly impact their performance on a daily basis. The fuzzy logic model can be used to:

- Predict and evaluate the overall foreman's performance (i.e. foreman's skills level), based on the characteristics of the foreman and his/her environment.
- Predict and evaluate the foreman's performance in each category of assessment.
- Compare the foreman's performance evaluation between different groups' assessments and identify gaps between them.
- Measure the effectiveness of a foreman among his/her crew members, supervisors, and peers in each area of responsibility.
- Contrast the foreman's performance evaluation between categories and identify areas that requires further training or mentoring of the foreman.
- Provide foremen with feedback on their skills and measure improvements over time.
- Identify training and mentoring required for a foreman to improve his/her skills in the core competencies.
- Measure the impact of training or mentoring on the skills of a foreman.
- Provide foremen with an opportunity to gain recognition for their skills.
- Help the construction industry or a company to identify site-wide or project-wide issues that may be affecting the ability of foremen to carry out their responsibilities.

## 7.3 Contributions and Benefits

This study has made a number of contributions in academic research and for the construction industry. Academically, the main contribution of this research is in developing a methodology for evaluating the performance of construction trades foremen. It also demonstrated the appropriateness of the application of fuzzy set theory in predicting and evaluating performance, despite facing different problems, and using the fuzzy logic technique to model subjective data collected for an actual performance evaluation project (Fayek and Poveda, 2008). Since the data collected in the performance study represents the type of data that would be collected within organizations, this research demonstrates how much data is required from the group assessments (e.g., foreman, supervisors and peers, and crew members) for predicting and evaluating performance. The methodology employed shows the involvement of different level within the organization to guarantee accurate results, it is recommended to collect data from the foreman, at least 2 supervisors and 2 peers, and all the foreman's crew members, however, guarantee the full participation of crew members could be a challenge, and for which a motivational plan must be developed.

This study also shows how fuzzy logic theory and fuzzy expert systems can be used to build performance models based on realistic data. A large numbers of factors affecting the foreman's performance were identified. The factors were divided in six categories to build the performance model. A process of converting numeric data into linguistic terms was also developed. This process involves translating subjective numeric values into linguistic variables, such as, very poor, poor, acceptable, good, and outstanding.

The membership functions and fuzzy rule bases were developed based on logical reasoning, without the availability of large data sets required to train, test, and validate the fuzzy logic model. This study demonstrated how to incorporate a number of factors to evaluate the foreman performance.

Furthermore, this research provides a basis for future work in predicting and evaluating the performance of construction trades foreman and construction workers in general, given the numerous factors affecting the performance of workforce. Since this problem is largely a subjective one, with non-mathematical relationships, fuzzy logic is an appropriate technique for modeling. This research has illustrated its usefulness in modeling the performance evaluation and prediction problem, and has laid the foundation for future research in this area.

Industrial contributions include the development of a model that provides insight into the factors that affect the foreman's performance evaluation and prediction. The fuzzy expert system developed provides a tool for performance evaluation and prediction, both of which are difficult to quantify and measure in the present conditions and existing tools in the industry. This fuzzy expert system may be useful to project management personnel in evaluating performance of employees (e.g., foremen); identifying areas of training needed, and recognizing workers for possible promotions, and for bonuses.

It also needs to be addressed the fact that the fuzzy logic model developed in this research allows the users (industry) to express themselves linguistically to evaluate performance of their personnel, which suits the way they normally express themselves.

There are a series of benefits for using the fuzzy model to evaluate and predict the foreman's performance (rather than using the statistical model, which is based on 7 linguistic descriptors). Some of these benefits are:

a) The fuzzy logic theory uses linguistic terms to obtain the foreman's evaluation rather than numeric results. In general, most individuals prefer to get their assessments in linguistic terms (e.g., very poor, poor, acceptable, good, and outstanding) than getting a numeric evaluation. Most of the time this numeric evaluations do not represent any logic in the scale used, because it may not be consistent in all evaluations or poorly explained. For example, obtaining a score of 3.0 in a scale of 1.0 to 7.0 basically only offers the conclusion that the individual is beyond the mean which is 4.0. Instead, using the fuzzy logic approach the results can be illustrated using linguistic results such as "poor or acceptable" depending on the categorization of the membership functions; which such results the necessity for improvement to reach the "good or outstanding" is easily interpreted.

b) Because of the structure of the fuzzy logic model there is a gradual transition between states making the system reacts smoothly to any variation that can be made in any of the variables of the model. Usually, the use of statistical models offer a numeric value that can be represented in a scale, this value can be translated to a meaningful linguistic scale. The fuzzy logic model offers results that can be interpreted making use of to what extent the value belongs to a linguistic terms. For example, the performance of an individual can be "acceptable" to some extent, and at the same time it can be also inferred that his performance is "outstanding" to some extent, which is called the degree of membership. The fuzzy logic model identifies the degree of membership for which the foreman is performing poorly or acceptably.

c) Because of the design adopted in the fuzzy logic model, the user is able to do intermediate analysis. Independent results for each category (e.g., safety, QA/QC, leadership and supervision, employee relations, planning and schedule, and administration) can be obtained in the model, which permit the user to analyze the results individually. Although each category can be analyzed separately, the model also offers an overall result to the user, so the foreman's overall performance evaluation is the aggregation of the results of all categories involved in the foreman's evaluation. Also, in each category, the evaluation of each group assessment (e.g., foreman, supervisors and peers, and crew members) can be analyzed separately; the model presents intermediate outputs for the user to make comparisons between groups.

d) In each category in the fuzzy logic model, the inputs are divided in three groups; foreman, supervisors and peers, and crew members. The fuzzy logic model allows the user to weight each group according to the user's desire by using the "Degree of Support" tool. The degree of support varied from 0 to 1. Value of 1 represents full contribution and 0 represents no contribution. For example, all group assessments have equal contribution in the evaluation of safety, the degree of support is equal to 1 for all groups. In case the supervisors and peers group has 50% participation the degree of support would be 0.50 while the other two groups (foreman and crew members) would share the other 50% participation. The degree of support is expressed in the rule blocks. The weighting depends on the validation of each group by the user; some might want to weight the supervisors and peers higher than the other two groups to eliminate any kind of bias.

e) The statistical approach (Fayek and Poveda, 2008) needs to calculate the results for each category; each one of these categories use between 6 to 20 questions to evaluate the performance of each foreman by the group assessment. The fuzzy logic model developed in this study proposes to re-group the question in each category according to a series of criteria mandate by the user. The fuzzy logic model developed in this study proposes to re-group the questions according to technical similarity among them providing a manageability characteristic for the model, Chapter 3 shows details of the re-grouping process of the questions. However. the user can re-group the questions using his/her criteria, each project and/or company poses unique characteristics and the foremen may face totally different challenges from project to project, this would affect his/her performance for which the criteria to re-group the questions may change.

f) The fuzzy logic model allows the user to trace back through the rules, which helps to determine the contribution of each factor (e.g., input variable) on the final results (e.g., assessment).

g) Since each company and/or project has unique characteristics, it is necessary to design a model that can generalize overall performance by group assessment, by evaluation category (e,g, safety, QA/QC, leadership and supervision, employee relations, planning and scheduling, and administration), and by foreman (e.g, overall performance evaluation). Furthermore, the fuzzy logic model can also distinguishe between assessments of different foremen by better capturing and evaluating their individual characteristics. These two features (generalization and distinction between assessments) can be accomplished by adjusting the the particular characteristics of the fuzzy rules and membership functions (e.g, rule weighting) to capture foreman-specific characteristics.

## 7.4 Limitations and Recommendations for Future Research

There are some limitations that this research faced, which affected the performance evaluation and prediction model development. These limitations need to be addressed to improve the model and its results obtained in this research. These limitations were identified in the following areas:

- Model design:

  This research study did not examine the impact of each variable on the overall performance, and how each factor affects each category in the model and each group assessment. In this study the author assumes that questions are equally weighted and affect the foreman's performance evenly, however, that may not be the case for each question in each category of assessment and in the foreman's overall performance.

- Data collection:

  Because of the particular characteristics of the company involved in the project, not enough data were collected to train the membership functions and rules, so the author could have applied other techniques such as Neuro Fuzzy. A better accuracy of the model (improving the percentage difference between the statistical and fuzzy logic model) may bring more confidence in the results. Although the percentage difference (e.g., error) obtained in this research demonstrated high accuracy of the fuzzy logic model, there is always improvements that can be done.

- Membership functions:

  Even though the membership functions selected produced good results in terms of percentage difference between statistical and fuzzy logic approaches (used to measure the accuracy of the model); the membership function development can improve by having a large set of data. Some techniques can be implemented to develop membership function: Heuristic methods, Pairwise comparison, Statistical methods, Methods based on clustering, Exemplification, Interpolation techniques (Dissanayake, 2006).

- Fuzzy expert system:

  The fuzzy expert system achieves a high rate of accuracy (e.g., percentage difference between statistical and fuzzy logic model); however, the software used in this research (e.g., Fuzzy-Tech) does not offer a large number of defuzzification methods. Since measure performance of human beings has not been researched enough using fuzzy logic, there is a necessity to explore the best deffuzification method to obtain higher accuracy of the model. The methods available in Fuzzy Tech are: CoM, fast CoA, MoM, and Hyper CoA. Other methods such as Bisector, Largest of Maxima, and Smallest of Maxima among others could offer new results.

A limitation encountered in this research relates to the validation of the model. It was assumed that the statistical model (Fayek and Poveda, 2008) offers valid (correct foreman's evaluation) results that were used to compare the values obtained using the fuzzy logic model. The accuracy of the model was measured as percentage difference between the statistical and fuzzy logic model. However, the values obtained using any of the models could not be considered for some as the real values for performance evaluation (since these models are based on subjective measures). There is an urge to do deeper research in performance evaluation to become with a more accurate procedure to evaluate performance if there is any. However, the author is confident that the fuzzy logic model developed in this research offers the best alternative to assess the performance of workforce.

Despite the limitations encountered in the development of the fuzzy logic model, this research provides very promising results for future research. The following are some recommendations for future research:

- The data collection process should incorporate larger projects and/or companies in order to get a larger set of data. A neuro-fuzzy approach can be used if the amount of data increases, the option of training the fuzzy logic model (training the membership function and rules) can improve the accuracy of the results. Neural networks can learn from data, but cannot be interpreted - they are black boxes to the user. Fuzzy Systems consist of interpretable linguistic rules, but they cannot learn. We use learning algorithms from the domain of neural networks to create fuzzy systems from data. The learning algorithms can learn both fuzzy sets, and fuzzy rules, and can also use prior knowledge.
- Objective performance measures should be incorporated in the model. The project control department of the companies usually collects objective data (e.g., PF, overtime %, punctuality) to measure the performance of their workforce (foremen). The author suggest to incorporate these ratings to the fuzzy logic model. For example, the safety category is evaluated by for factors (inputs in the fuzzy model), other inputs (e.g., near hit rate %, incident rate %) can be incorporated to complement the evaluation, these factors can bring the objectivity than a self-responded questionnaire may not have. Furthermore, the second option is to have parallel models working independently; one fuzzy logic model evaluating the objective data (project control factors) and another fuzzy logic model evaluating the self-responded questionnaires, the results of both models can be interpreted independently or integrate them to obtain one overall output.
- To increase the confidence in the results of fuzzy logic model, cross validation can also be used, that is, repeat the data collection using the same group participating in the first place.

- More research needs to be done on the variables involved in the foreman's performance evaluation. These variables were re-grouped according to a series of criteria. A further research on these criteria, variables (factors that affect the foreman's performance) and categories to evaluate the foreman performance should be conducted. Different relative importance weightings of the variables should be explored.
- For membership function generation, although various shapes were tested (e.g., sensitivity analysis), some other techniques of membership function generation should be explored to identify if the accuracy of the model can be improved.
- It is recommended to use in future research not only correlation analysis but also a non-linear regression to explore the effect of partial correlation between input factors and for differential weighting of the rules. Furthermore, it is suggested a further analysis of the impact of each category in the overall performance output, and also investigate the impact of each group assessment in each category output evaluation.
- Generation of If-Then rules can be improved by collecting a larger data set (larger set of data allows training the rule base using the neuro-fuzzy technique) and by involving the expert's opinion. The author created the fuzzy rules base making use of his own criteria, experts such as construction managers, professors could help to develop this rule base in further research. Thus, the accuracy of the actual rules in the fuzzy logic model may be improved significantly.
- To improve the accuracy of the model, a different defuzzification method may need to be developed. Instead of using the available methods in Fuzzy-Tech, the defuzzification methods existing are extensive, but because the software is limited to four methods (CoA, CoM, HyperCoA, MoM) the model was not tested using these other defuzzification methods. It is uncertain if the accuracy would be improved using any other different defuzzification method.

This study is one of the very few that has been done in the area of industrial construction to evaluate and predict performance of workforce using fuzzy logic and fuzzy expert systems. It is hoped that this study provide the basis for future research, while taking into consideration the highlights encountered in this study.

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## Appendix A: Foreman Job Description (Construction Owners Association of Alberta - COAA, 2007)

Areas of Safety, Leadership and Supervision, Planning and Scheduling, Labour Relations, Quality Control, and Administration have been identified as the foremen's area of responsibilities by COAA Supervisory Training and Qualifications Subcommittee.

Each area has been identify and defined to make clear and ensure that the foreman can performance according to the company expectations;

**Safety:** The foreman must facilitate a safe work culture, is accountable for the safety of the crew and must understand the legal liability of the role; ensuring crewmembers apply the standards for safe working conditions and are fit for work each day.

**Responsibilities**

- Knowing, understanding, communicating and ensuring compliance with the safety regulations (Occupational Health and Safety Act) and safety policies and procedures.
- Identifying needs, and providing or arranging for, crew safety training.
- Conducting "safety tool box" meeting.
- Completing initial safety and hazard assessments (Field Level Risk Assessments [FLRAs]).
- Providing answers to any technical safety questions.
- Participating in safety/incident investigations and reviews.
- Completing incident and other safety reports

**Leadership and Supervision:** the foreman leads the crew and is accountable for how the crew completes the assigned work, and must understand and consistently apply the employer's policies.

**Responsibilities**

- Ensuring new crew members are oriented to the job.
- Assessing competency and capability of tradespersons; evaluating crew capability and benchmarking to others to ensure that the crew meets required levels of quality.
- Communicating the job to and with the crew.
- Assigning individual and crew tasks.
- Training and mentoring crew members in specific tasks.
- Coordinating on the job training for apprentices and facilitating mentoring of apprentices by journeymen.
- Recognizing, addressing and resolving issues/problems among/between crew(s).
- Setting and maintaining work standards and outlining behavioral expectations to ensure crew morale and productivity.
- Applying the company's corrective action policy where applicable.
- Applying project procedures, worksite policies and collective agreement requirements.

**Planning and Scheduling:** The foreman is accountable for following project plans and schedules and ensuring the crew's daily and weekly activities meet production goals.

**Responsibilities**

- Identifying and/or verifying that the field installation work package (FIWP), which includes all tools and materials required by the crew are available and complete.
- Identifying needs and deficiencies in the plan/schedule and communicating these to the appropriate persons.
- Translating general work requirements into a prioritized plan for individual tasks and assignments.
- Reviewing and adjusting specific workface activities and task schedules to meet established production schedules.
- Working with the crew to overcome work challenges.

- Resolving. Or if unable to resolve, reporting any scheduling conflicts with others crews and contractors to the appropriate persons.

**Labour Relations:** The foreman must champion an inclusive labour relations culture and is accountable for the adherence to Labour Relations policies and procedures by the crew under his/her direction.

**Responsibilities**

- Knowing, understanding, communicating and ensuring compliance with all project labour relation requirements as it relates to labour relations policies, procedures and programs.
- Identifying needs for crew labour relations training and facilitates delivery of training.
- Expediting answers to any labour relations questions.
- Ensuring a respectful and inclusive labour relation work environment.
- Understanding the importance of apprenticeship training.
- Ensuring that the project labour relation manager or designate is included in all major, potentially controversial or questionable labour relation matters. Labour relation manager or designates advice is sought in a timely manner and is applied consistently and fairly.
- Participating in labour relation incident investigations and reviews when requested.
- Promoting, supporting and facilitating teamwork and harmony between all construction crews by promoting and fostering a positive, visible teamwork attitude among all project crews, regardless of craft makeup.

**Quality Control:** The foreman is accountable for ensuring the work done meets standards and for recommending work processes to improve productivity and product quality.

**Responsibilities**

- Overseeing the executing of the work, including quality and production, by ensuring that the crew works to job specifications and follows the blueprints.
- Inspecting completed work and initiating timely resolutions.

**Administration:** The foreman is accountable for the preparation of reports as requires by the employer".

**Responsibilities**

- Requisitioning supplies to address any deficiencies in FIWPs
- Maintaining foreman's log or dairies.
- Reporting on workface production and work progress.
- Completing quality reports.
- Completing required statistics.
- Obtaining permits.
- Time keeping and time cards, including recording late starts/early starts.
- Distributing cheques and handling problems with cheques.
- Recommending personnel actions such as hiring, promotions and discipline.

The responsibilities in each area have been specified by the Supervisory Training and Qualifications Subcommittee; these responsibilities are shown in the next table;

The six areas described previously are the areas of responsibility for the construction trade foreman; some other characteristics a form part of the role, such as knowledge, skills, attitude and qualifications. For the Constructors Owners Association of Alberta, the foreman needs to have the following characteristics:

Table 1 Characteristics of Foreman

| Area | Characteristics |
|---|---|
| **Knowledge** | Knows and understands: |
| | Company and project safety programs. |
| | Occupational health and safety and environmental issues. |
| | Workers' Compensation Board and insurance (health and welfare/disability) provisions. |
| | Collective agreement, employment standards and company policies. |
| | How to read blue prints. |
| | Scope of both one's own and other construction trades. |
| **Skills** | Has the ability to: |
| | Lead the crew. |
| | Effectively communicate orally and in writing, with good comprehension. |
| | Coach and teach crew members. |
| | Assess crew skills. |
| | Apply good problem solving and conflict resolution skills. |
| | Manage differences and diversity at the work site. |
| | See how the work and tasks fits into the project. |
| | Form and implement workface crew plans and schedules. |
| | Organize and delegate work. |
| | Handle the administrative duties of position, including completion of required documents. |
| | Effectively use computers and other technology. |
| **Attitude** | Shows that she/he: |
| | Is ready to take on new challenges and is willing to learn. |
| | Has good work ethics. |
| | Can adjust to change. |
| | Can be a role model who leads by example. |
| | Is willing to motivate and mentor crew members. |
| | Is a team player. |
| | Takes responsibility. |
| | Is honest and acts with integrity. |

Independent of responsibilities and characteristics the Supervisory Training and Qualifications Subcommittee has identified the qualifications of the foreman, some of these are describe in the next table:

**Table 2 Qualifications of Foreman**

| Qualifications |
|---|
| Has completed leadership for Safety Excellence. |
| Has completed Construction Safety Training Systems (CSTS). |
| Has a current Standard First Aid certificate. |
| Has completed a formal supervisory training program (e.g., Better Supervision, Merit Supervisory Training Program) or equivalent. |
| Has 3 to 5 years experience as a qualified and competent tradesperson, who is familiar with other construction trades and crafts. |

## Appendix B: Sample of Questionnaires: Foreman (Self-Evaluation) Manual

# CONSTRUCTION OWNERS ASSOCIATION OF ALBERTA

# FOREMAN SKILLS DEVELOPMENT TOOL

# FOREMAN (SELF-EVALUATION) MANUAL

**Name of Foreman:**________________________________ **Date:**______/______/______
Day Month Year

**Trade:**______________________

## Objectives of Foreman Skills Development Tool

The Construction Trades Foreman provides leadership, schedules, coordinates, supervises, and ensures the safety and productivity of crews at the workface who install/assemble components of industrial products and structures. As a key participant in the relationship with the contractor, company, and client, the foreman acts as management liaison and client interface.

The objective of the Foreman Skills Development Tool is to help you and your employer identify your areas of strengths and areas requiring further improvement in 6 specific areas of responsibility: Safety, Planning and Scheduling, Leadership and Supervision, Employee Relations, QA/QC (Quality Assurance/Quality Control), and Administration.

For each of these areas, there are approximately 10 to 20 questions that identify your abilities, knowledge, skills, company commitment, and behaviour. We would like you to evaluate yourself according to these questions. Similar evaluations will be sought from your crew members and your supervisors. All of these responses will be compiled and related to relevant project performance data for activities under your supervision. You will be asked to undertake this assessment process periodically throughout the duration of your employment.

The information collected through this Tool will be used to help you identify your supervisory strengths so that you can build on them, identify areas that need improvement and may be addressed through further training or mentoring, monitor your improvements over time, and gain recognition towards promotional opportunities.

Additionally, the information will help your employer identify common areas of concern for all foremen, which may be addressed through company-wide or industry-wide supervisory training efforts. The information may also help your employer identify project-wide issues, which may be addressed through project management efforts, to provide continuous improvement of their own practices.

## Foreman Qualifications Summary (to be completed once)

In order to establish your initial qualifications, please complete the following questions. If you have completed this section previously, please proceed to the page entitled "**Scale to Use for Skills Evaluation**".

**Your Age Group**

19 and under ______
20-25 ______
26-30 ______
31-35 ______
36-40 ______
41-45 ______
46-50 ______
51-55 ______
56-60 ______
61 and over ______

**Construction Work Experience**

Please indicate your cumulative construction work experience in years.

| Company Name (optional) | Last year of employment (optional) | Industrial Construction | | |
|---|---|---|---|---|
| | | On tools | As a Foreman | As a General Foreman |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

| Company Name (optional) | Last year of employment (optional) | Industrial Maintenance | | |
|---|---|---|---|---|
| | | On tools | As a Foreman | As a General Foreman |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

| Company Name (optional) | Last year of employment (optional) | Commercial Construction | | |
|---|---|---|---|---|
| | | On tools | As a Foreman | As a General Foreman |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

| Company Name (optional) | Last year of employment (optional) | Other (specify): | | |
|---|---|---|---|---|
| | | On tools | As a Foreman | As a General Foreman |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Formal Education**

Please indicate which categories of formal education you have experienced.

| | Started | Completed | Year Completed | Degree Obtained |
|---|---|---|---|---|
| High School | | | | |
| Apprenticeship/Trade Program | | | | |
| College | | | | |
| University | | | | |
| Other (specify): | | | | |
| | | | | |
| | | | | |

**Formal Training**

Please indicate which of these formal training programs you have completed.

| | | If yes, when completed? | | |
|---|---|---|---|---|
| | Completed | Within last year? | Within last 3 years? | More than 3 years ago? |
| Construction Safety Training Systems (CSTS) | | | | |
| Standard First Aid | | | | |
| Formal Supervisory Training Program (e.g. Better Supervision, Merit Supervisory Training Program, or equivalent) | | | | |
| Leadership for Safety Excellence (ACSA) | | | | |
| The Alcohol and Drug Policy that Works – Supervisor's Workshop (CLRA) | | | | |
| Leaders Building Leaders (CLRA) | | | | |
| Other (specify): | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Additional Training and Education**

Please indicate if you have had formal education or training in the supervisory topics listed below, and indicate how recently you received this training.

| | | If yes, most recent formal education or training on this topic? | | |
|---|---|---|---|---|
| | Have had formal education or training on topic | Within last year? | Within last 3 years? | More than 3 years ago? |
| Leadership | | | | |
| Motivation | | | | |
| Oral Communication | | | | |
| Written Communication | | | | |
| Problem Solving | | | | |
| Decision Making | | | | |
| Planning and Scheduling | | | | |
| Cost Control | | | | |
| Productivity Improvement | | | | |
| Project Management | | | | |
| Construction Law | | | | |
| Using Contract Documents | | | | |
| Coaching | | | | |
| Mentoring | | | | |
| Safety | | | | |
| Quality Assurance/Quality Control | | | | |
| Hazardous Materials | | | | |
| Alcohol and Drug Abuse | | | | |
| Other (specify): | | | | |
| | | | | |
| | | | | |
| | | | | |

**Training and/or Education Within Past Six Months**

Is there any additional training and/or education you have received from the company within the past six months?

Yes ______ No _______

If yes, please describe the training or education you received.

| Description | Duration | Start date |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

## Computer Training

Please indicate the level of your working knowledge of each of the software applications listed below.

| | Level of Working Knowledge | | | |
|---|---|---|---|---|
| | Low | Average | High | Do Not Use |
| Word processing (e.g. Word, WordPerfect) | | | | |
| Spreadsheets (e.g. Excel) | | | | |
| Databases (e.g. Access) | | | | |
| E-mail (e.g. Outlook) | | | | |
| Internet (e.g. Explorer) | | | | |
| Scheduling (e.g. Project, Primavera) | | | | |
| Other (specify): | | | | |
| | | | | |
| | | | | |
| | | | | |

## Additional Experience

Please answer the following questions related to other experience you may have had.

| | Yes | No |
|---|---|---|
| Aside from formal "classroom" training, have you ever learned supervisory topics through formal "on-the-job" training (structured as opposed to "sink-or-swim")? | | |
| | | |
| Have you ever been "mentored" in a formal mentoring program? | | |
| | | |
| Have you ever been an instructor for supervisory courses? | | |
| | | |
| Have you ever coached athletic teams of any type (e.g. children's or adults' teams)? | | |
| | | |
| Have you ever held other leadership roles of any type (e.g. Scout leader, Big Brother, Big Sister, etc.)? | | |
| | | |
| Have you ever served in the military or military reserves? | | |

**Are there any aspects of your project(s) or day-to-day tasks that are out of your control and that may affect your ability to carry out your responsibilities? Please comment below.**

## Scale to Use for Skills Evaluation

For each of the following questions, please evaluate the level of your skills using the following scale. If you do not perform the task included in a question, please choose the "**Not Applicable/Do Not Perform**" column for that question.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Extremely Low | Quite Low | Slightly Low | Neither Low Nor High | Slightly High | Quite High | Extremely High |

**Extremely Low**: You do not have the skills or knowledge required for this task, and you would like training.

**Quite Low**: You have very few of the skills or knowledge required for this task, and you would like training.

**Slightly Low**: You have few of the skills or knowledge required for this task, and you would like training.

**Neither Low Nor High**: You have adequate skills or knowledge required for this task, but you would like to improve with further training.

**Slightly High**: You have many of the skills or knowledge required for this task, and you are generally interested in improving.

**Quite High:** You have the majority of the skills or knowledge required for this task.

**Extremely High:** You have all of the skills or knowledge required for this task, and you are setting the standard for others.

## Safety

Safety is defined as the state of being safe or protected against physical, social, financial, emotional, occupational, psychological, or others types of harm resulting from failure, damage, error, or accidents. Safety is often in relation to ensuring a certain standard in terms of safety incidents, which is often associated with the quality of the organization.

### Foreman's Responsibilities

The foreman must facilitate a safe work culture, is accountable for the safety of the crew, and must understand the legal liability of the role. The foreman must ensure that crew members apply the standards for safe working conditions and are fit for work each day.

|  |  | Skills Evaluation |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | **Safety** | Not Applicable/ I Do Not Perform | Extremely Low | Quite Low | Slightly Low | Neither Low Nor High | Slightly High | Quite High | Extremely High |
|  | **To what extent do you think you:** | **N/A** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| S1. | Have a good understanding of HSE good practices and procedures? |  |  |  |  |  |  |  |  |
| S2. | Are knowledgeable in Workers' Compensation Board and insurance provisions? |  |  |  |  |  |  |  |  |
| S3. | Support the company safety program? |  |  |  |  |  |  |  |  |
| S4. | Emphasize safe work practices? |  |  |  |  |  |  |  |  |
| S5. | Communicate safety policies and procedures? |  |  |  |  |  |  |  |  |
| S6. | Complete initial safety and hazard assessments (e.g., FLRAs)? |  |  |  |  |  |  |  |  |
| S7. | Develop safe work plans for your crew members? |  |  |  |  |  |  |  |  |
| S8. | Correctly answer technical safety questions from your crew? |  |  |  |  |  |  |  |  |
| S9. | Conduct safety tool box meetings? |  |  |  |  |  |  |  |  |
| S10. | Identify and arrange for crew safety training? |  |  |  |  |  |  |  |  |
| S11. | Participate in safety/incident investigations and reviews? |  |  |  |  |  |  |  |  |
| S12. | Complete your incident and other safety reports? |  |  |  |  |  |  |  |  |
| S13. | Enforce the company drug and alcohol policy? |  |  |  |  |  |  |  |  |

FLRA = Field Level Risk Assessment

HSE = Health, Safety, and Environment

**Please provide any additional comments below:**

## Quality Assurance (QA) and Quality Control (QC)

**QA/QC** (Quality Assurance and Quality Control): The QA/QC program has two components: **Quality Assurance (QA)** – the system used to verify that the entire analytical process is operating within acceptable limits, using measurement programs to evaluate processes; **Quality Control (QC)** – the mechanisms established to measure non-conforming methods performance, and to verify that specific attributes are in a certain product or service.

### Foreman's Responsibilities

The foreman is accountable for ensuring the work done meets standards, and for recommending work processes to improve productivity and product quality.

|  |  | Skills Evaluation |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | **QA/QC** | Not Applicable/ I Do Not Perform | Extremely Low | Quite Low | Slightly Low | Neither Low Nor High | Slightly High | Quite High | Extremely High |
|  | **To what extent do you think you:** | **N/A** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| Q1. | Understand the company's QA/QC expectations? |  |  |  |  |  |  |  |  |
| Q2. | Effectively resolve technical and QA/QC issues? |  |  |  |  |  |  |  |  |
| Q3. | Ensure that the crew is working according to the company's QA/QC specifications? |  |  |  |  |  |  |  |  |
| Q4. | Ensure that the crew is working according to job specifications and blueprints? |  |  |  |  |  |  |  |  |
| Q5. | Ensure that the correct tools and equipment are utilized? |  |  |  |  |  |  |  |  |
| Q6. | Inspect the completed work and initiate corrective action if needed? |  |  |  |  |  |  |  |  |

QA = Quality Assurance
QC = Quality Control

**Please provide any additional comments below:**

## Leadership and Supervision

**Leadership:** Leadership is defined as the ability of an individual to set an example for others and provide direction. Leadership is also defined as the ability of an individual to influence, motivate, and enable others to contribute toward the effectiveness and success of the project or organization of which they are members.

**Supervision:** Supervision is the act of watching over the work or task of another who may lack full knowledge of the concept at hand. Supervision does not mean control of another, but rather guidance in a work, professional, or personal context.

### Foreman's Responsibilities

The foreman leads the crew and is accountable for how the crew completes the assigned work, and must understand and consistently apply the employer's policies.

| | | Skills Evaluation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Leadership and Supervision** | Not Applicable/ I Do Not Perform | Extremely Low | Quite Low | Slightly Low | Neither Low Nor High | Slightly High | Quite High | Extremely High |
| | **To what extent do you think you:** | **N/A** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| L1. | Have good oral communications skills? | | | | | | | | |
| L2. | Have good written communication skills? | | | | | | | | |
| L3. | Are punctual and consistently present at work? | | | | | | | | |
| L4. | Promote pride in workmanship? | | | | | | | | |
| L5. | Are knowledgeable of your trade's scope of work? | | | | | | | | |
| L6. | Are knowledgeable of other trades' scope of work? | | | | | | | | |
| L7. | Are skilled at reading and applying blueprints and specifications? | | | | | | | | |
| L8. | Are responsible and reliable? | | | | | | | | |
| L9. | Have good work ethics, integrity, and honesty? | | | | | | | | |
| L10. | Are able to make good decisions on time? | | | | | | | | |
| L11. | Are able to adapt to change and be flexible? | | | | | | | | |
| L12. | Set a good example of behaviour and work standards to help ensure crew morale and productivity? | | | | | | | | |
| L13. | Work in a group or as part of a team? | | | | | | | | |
| L14. | Assess the capabilities and interests of your crew members? | | | | | | | | |
| L15. | Match task assignments to your individual crew members' capabilities and interests? | | | | | | | | |
| L16. | Explain to your crew their responsibilities and duties? | | | | | | | | |
| L17. | Anticipate and avoid problems? | | | | | | | | |
| L18. | Promote teamwork and harmony between all construction crews and trades? | | | | | | | | |
| L19. | Ensure that new crew members are oriented to the job? | | | | | | | | |
| L20. | Coordinate on the job training for apprentices and facilitate mentoring of apprentices by journeymen? | | | | | | | | |

**Please provide any additional comments below:**

## Employee Relations

The field of employee relations looks at the relationship between management and workers. The foreman should know, understand, communicate, and ensure that the members in his/her crew understand company employee relations policies, procedures, and programs. The foreman should identify which members are in need of training and help to facilitate such training.

The foreman should also promote, support, and facilitate teamwork and harmony between all construction crews by promoting and fostering a positive, visible teamwork attitude among all project crews, regardless of craft makeup.

### Foreman's Responsibilities

The foreman must champion an inclusive employee relations culture and is accountable for the adherence to employee relations policies and procedures by the crew under his/her direction.

|  |  | Skills Evaluation |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | **Employee Relations** | Not Applicable/ I Do Not Perform | Extremely Low | Quite Low | Slightly Low | Neither Low Nor High | Slightly High | Quite High | Extremely High |
|  | **To what extent do you think you:** | **N/A** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| R1. | Respect your crew members? |  |  |  |  |  |  |  |  |
| R2. | Consult with and include your crew members in discussions on how to carry out the work? |  |  |  |  |  |  |  |  |
| R3. | Coordinate and communicate with other trades? |  |  |  |  |  |  |  |  |
| R4. | Recognize, address, and resolve issues/problems within your crew or between crews? |  |  |  |  |  |  |  |  |
| R5. | Identify training needs for your crew and facilitate delivery of the training and mentoring programs? |  |  |  |  |  |  |  |  |
| R6. | Ensure a respectful and inclusive employee relations work environment? |  |  |  |  |  |  |  |  |
| R7. | Know/understand, communicate, and ensure compliance with the company's employee relations policies? |  |  |  |  |  |  |  |  |
| R8. | Ensure that the Project Employee Relations Manager or designate is included in all major potentially controversial or questionable employee relations matters, and that his/her advice is applied consistently and fairly? |  |  |  |  |  |  |  |  |
| R9. | Document performance problems of crew members? |  |  |  |  |  |  |  |  |
| R10. | Investigate and document incidents with crew members accurately and thoroughly? |  |  |  |  |  |  |  |  |
| R11. | Apply the company's corrective action policy where applicable? |  |  |  |  |  |  |  |  |
| R12. | Apply project procedures, worksite policies, and collective agreement requirements? |  |  |  |  |  |  |  |  |

**Please provide any additional comments below:**

## Planning and Scheduling

**Planning:** Planning is the process of defining the scope and sequence of activities required to get the work done and to create a desired outcome. The planning thought process is essential to the creation and refinement of a plan, or its integration with other plans.

**Scheduling:** Scheduling is the process of timing the activities that need to be completed, and determining the necessary manpower, tools, equipment, and material to get the work done.

### Foreman's Responsibilities

The foreman is accountable for following project plans and schedules and ensuring the crew's daily and weekly activities meet production goals set by the company.

|  |  | Skills Evaluation |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|
|  | **Planning and Scheduling** | Not Applicable/ I Do Not Perform | Extremely Low | Quite Low | Slightly Low | Neither Low Nor High | Slightly High | Quite High | Extremely High |
|  | **To what extent do you think you:** | **N/A** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| P1. | Understand and apply project schedules? |  |  |  |  |  |  |  |  |
| P2. | Identify needs and deficiencies in the plan/schedule and communicate them to the right person? |  |  |  |  |  |  |  |  |
| P3. | Participates in preparing weekly and look-ahead schedules? |  |  |  |  |  |  |  |  |
| P4. | Translate work requirements into a plan for individual tasks, and assign them to crew members (delegate)? |  |  |  |  |  |  |  |  |
| P5. | Communicate the plan, schedule, and scope of work to your crew members? |  |  |  |  |  |  |  |  |
| P6. | Plan manpower requirements? |  |  |  |  |  |  |  |  |
| P7. | Plan scaffold requirements? |  |  |  |  |  |  |  |  |
| P8. | Plan ahead your work to minimize delays in schedule? |  |  |  |  |  |  |  |  |
| P9. | Identify/verify that all tools and materials (FIWPs) are available and complete? |  |  |  |  |  |  |  |  |
| P10. | Review/adjust specific workface activities and task schedules to meet established production schedules? |  |  |  |  |  |  |  |  |
| P11. | Work with the crew to overcome work challenges? |  |  |  |  |  |  |  |  |
| P12. | Work towards meeting weekly schedule/production targets? |  |  |  |  |  |  |  |  |
| P13. | Work towards meeting weekly productivity targets (e.g., Performance Factors)? |  |  |  |  |  |  |  |  |
| P14. | Identify and attempt to resolve road blocks to productivity? |  |  |  |  |  |  |  |  |
| P15. | Resolve, or else report, schedule problems or conflicts with other crews or contractors? |  |  |  |  |  |  |  |  |

FIWP = Field Installation Work Package

**Please provide any additional comments below:**

## Administration

Administration consists of company processes required for organization, efficiency, quality, standards, and procedures. It involves record keeping, reporting, and maintaining of quality standards and procedures to help enhance the function of the company and/or project.

### Foreman's Responsibilities

The foreman is accountable for the preparation of reports as required by the employer or supervisor.

| | | Skills Evaluation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Administration** | Not Applicable/ I Do Not Perform | Extremely Low | Quite Low | Slightly Low | Neither Low Nor High | Slightly High | Quite High | Extremely High |
| | **To what extent do you think you:** | **N/A** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| A1. | Keep and update logs or diaries as required? | | | | | | | | |
| A2. | Maintain accurate time cards? | | | | | | | | |
| A3. | Report the workface production and work progress? | | | | | | | | |
| A4. | Complete quality reports? | | | | | | | | |
| A5. | Complete the statistics required by the company? | | | | | | | | |
| A6. | Complete your reports in a clear and easy to understand manner? | | | | | | | | |
| A7. | Requisition supplies on time to address deficiencies in tools and materials (i.e., FIWPs)? | | | | | | | | |
| A8. | Obtain permits on time? | | | | | | | | |
| A9. | Distribute cheques and effectively handle problems with cheques? | | | | | | | | |
| A10. | Recommend personnel actions (e.g. hiring, promotions, discipline)? | | | | | | | | |
| A11. | Use computers, if required? | | | | | | | | |

FIWP = Field Installation Work Package

**Please provide any additional comments below:**

## Appendix C: Selection Form for Foreman's Supervisors and Peers

Foreman's Name: ____________________

Please identify one of each of the following people to assess your skills. In the case of other foremen, please provide the names of 2 or 3 foremen with whom you interact or who know your work.

Superintendent: ____________________

General Foreman: ____________________

QA/QC Representative: ____________________

Safety Representative: ____________________

Materials Management Representative: ____________________

Other Foremen: ____________________

____________________

____________________

## Appendix D: Rating by Category Using the Statiscal Model

(1) Safety

RATING BY CATEGORY
SAFETY

| | Foreman | | Supervisors and Peers | | Crew Members | | |
|---|---|---|---|---|---|---|---|
| | Mean | # of participants | Mean | # of participants | Mean | # of participants | Overall Mean |
| **Foreman Code** | | | | | | | |
| F1200 MY | 4.92 | 1 | 3.43 | 2 | 4.93 | 9 | 4.68 |
| F1300 MY | 4.38 | 1 | 4.66 | 4 | 5.48 | 16 | 5.27 |
| F1400 MY | 5.00 | 1 | 5.42 | 6 | 5.57 | 5 | 5.45 |
| F1500 MY | 6.00 | 1 | 5.06 | 6 | 6.36 | 11 | 5.91 |
| F1600 MY | 4.80 | 1 | 4.53 | 5 | 6.38 | 6 | 5.48 |
| F1700 MY | 5.69 | 1 | 5.74 | 5 | 5.72 | 8 | 5.73 |
| F1800 MY | 5.69 | 1 | 5.92 | 2 | 5.90 | 2 | 5.87 |
| F1900 MY | 4.25 | 1 | 5.74 | 3 | 4.99 | 3 | 5.21 |
| F2000 MY | 4.08 | 1 | 4.75 | 4 | 6.11 | 7 | 5.49 |
| F2100 MY | 5.46 | 1 | 5.17 | 5 | 5.49 | 17 | 5.42 |
| F2200 MY | 4.90 | 1 | 4.65 | 4 | 5.00 | 21 | 4.94 |
| F5200 FS | 6.38 | 1 | 5.37 | 4 | 4.75 | 4 | 5.21 |
| F5300 FS | 5.69 | 1 | 5.37 | 6 | 5.67 | 6 | 5.53 |
| F5400 FS | 5.08 | 1 | 5.79 | 5 | 4.61 | 6 | 5.14 |
| F5500 FS | 5.73 | 1 | 5.80 | 6 | 5.83 | 8 | 5.81 |
| F5600 FS | 5.33 | 1 | 5.16 | 3 | 5.77 | 5 | 5.52 |
| F5700 FS | 5.60 | 1 | 5.45 | 3 | 5.59 | 2 | 5.52 |

| | |
|---|---|
| **Company's Overall Mean** | **5.42** |
| **Company's Overall Median** | **5.48** |

(2) QA/QC

### RATING BY CATEGORY
### QA/QC

| | Foreman | | Supervisors and Peers | | Crew Members | | |
|---|---|---|---|---|---|---|---|
| | Mean | # of participants | Mean | # of participants | Mean | # of participants | Overall Mean |
| Foreman Code | | | | | | | |
| F1200 MY | 4.00 | 1 | 3.50 | 2 | 4.76 | 9 | 4.49 |
| F1300 MY | 4.83 | 1 | 4.38 | 4 | 5.57 | 16 | 5.31 |
| F1400 MY | 4.50 | 1 | 5.43 | 6 | 5.37 | 5 | 5.33 |
| F1500 MY | 4.17 | 1 | 4.96 | 6 | 6.21 | 11 | 5.68 |
| F1600 MY | 4.67 | 1 | 4.58 | 5 | 6.51 | 6 | 5.55 |
| F1700 MY | 6.00 | 1 | 5.38 | 5 | 6.25 | 8 | 5.92 |
| F1800 MY | 5.33 | 1 | 5.60 | 2 | 5.12 | 2 | 5.35 |
| F1900 MY | 5.80 | 1 | 6.08 | 3 | 6.06 | 3 | 6.03 |
| F2000 MY | 4.50 | 1 | N/A | 4 | 6.29 | 11 | 6.14 |
| F2100 MY | 6.17 | 1 | 4.97 | 5 | 5.64 | 17 | 5.52 |
| F2200 MY | 4.50 | 1 | 4.50 | 4 | 5.28 | 21 | 5.13 |
| F5200 FS | 6.25 | 1 | 5.83 | 4 | 5.08 | 4 | 5.54 |
| F5300 FS | 6.67 | 1 | 5.79 | 6 | 5.75 | 6 | 5.84 |
| F5400 FS | 5.83 | 1 | 5.46 | 5 | 4.61 | 6 | 5.07 |
| F5500 FS | 6.00 | 1 | 5.57 | 6 | 5.11 | 8 | 5.35 |
| F5600 FS | 5.83 | 1 | 5.29 | 3 | 5.73 | 5 | 5.59 |
| F5700 FS | 5.67 | 1 | 5.34 | 3 | 6.00 | 2 | 5.62 |

| | |
|---|---|
| **Company's Overall Mean** | **5.50** |
| **Company's Overall Median** | **5.54** |

(3) Leadership and Supervision

## RATING BY CATEGORY
## LEADERSHIP AND SUPERVISION

| | Foreman | | Supervisors and Peers | | Crew Members | | |
|---|---|---|---|---|---|---|---|
| | Mean | # of participants | Mean | # of participants | Mean | # of participants | Overall Mean |
| **Foreman Code** | | | | | | | |
| F1200 MY | 4.80 | 1 | 4.37 | 2 | 4.78 | 9 | 4.71 |
| F1300 MY | 4.50 | 1 | 4.51 | 4 | 5.40 | 16 | 5.19 |
| F1400 MY | 5.15 | 1 | 4.85 | 6 | 4.95 | 5 | 4.92 |
| F1500 MY | 4.45 | 1 | 4.89 | 6 | 6.21 | 11 | 5.67 |
| F1600 MY | 5.10 | 1 | 4.95 | 5 | 6.26 | 6 | 5.62 |
| F1700 MY | 5.70 | 1 | 5.93 | 5 | 6.13 | 8 | 6.03 |
| F1800 MY | 5.65 | 1 | 6.42 | 2 | 5.75 | 2 | 6.00 |
| F1900 MY | 5.40 | 1 | 5.60 | 3 | 5.46 | 3 | 5.51 |
| F2000 MY | 4.74 | 1 | 5.03 | 4 | 6.2 | 11 | 5.82 |
| F2100 MY | 5.89 | 1 | 5.44 | 5 | 5.44 | 17 | 5.46 |
| F2200 MY | 5.30 | 1 | 4.64 | 4 | 5.08 | 21 | 5.02 |
| F5200 FS | 6.44 | 1 | 5.93 | 4 | 5.09 | 4 | 5.61 |
| F5300 FS | 6.00 | 1 | 5.68 | 6 | 6.05 | 6 | 5.88 |
| F5400 FS | 4.45 | 1 | 5.68 | 5 | 4.02 | 6 | 4.75 |
| F5500 FS | 6.58 | 1 | 5.79 | 6 | 5.49 | 8 | 5.68 |
| F5600 FS | 5.85 | 1 | 5.19 | 3 | 6.01 | 5 | 5.72 |
| F5700 FS | 5.68 | 1 | 5.71 | 3 | 5.76 | 2 | 5.72 |

| | |
|---|---|
| **Company's Overall Mean** | **5.49** |
| **Company's Overall Median** | **5.62** |

(4) Employee Relations

### RATING BY CATEGORY
### EMPLOYEE RELATIONS

| Foreman Code | Foreman | | Supervisors and Peers | | Crew Members | | |
|---|---|---|---|---|---|---|---|
| | Mean | # of participants | Mean | # of participants | Mean | # of participants | Overall Mean |
| F1200 MY | 3.83 | 1 | 4.03 | 2 | 4.30 | 9 | 4.22 |
| F1300 MY | 4.17 | 1 | 3.93 | 4 | 5.19 | 16 | 4.90 |
| F1400 MY | 4.25 | 1 | 4.42 | 6 | 4.78 | 5 | 4.56 |
| F1500 MY | 4.30 | 1 | 4.42 | 6 | 6.64 | 11 | 5.77 |
| F1600 MY | 4.30 | 1 | 4.73 | 5 | 6.13 | 6 | 5.39 |
| F1700 MY | 5.18 | 1 | 4.85 | 5 | 5.89 | 8 | 5.47 |
| F1800 MY | 5.33 | 1 | 6.00 | 2 | 5.67 | 2 | 5.73 |
| F1900 MY | 4.33 | 1 | 5.29 | 3 | 4.75 | 3 | 4.92 |
| F2000 MY | 4.33 | 1 | 4.57 | 4 | 6.21 | 11 | 5.68 |
| F2100 MY | 4.70 | 1 | 5.29 | 5 | 5.45 | 17 | 5.38 |
| F2200 MY | 4.78 | 1 | 4.15 | 4 | 4.96 | 21 | 4.83 |
| F5200 FS | 6.25 | 1 | 5.54 | 4 | 4.61 | 4 | 5.21 |
| F5300 FS | 5.42 | 1 | 5.50 | 6 | 5.73 | 6 | 5.60 |
| F5400 FS | 4.58 | 1 | 5.75 | 5 | 4.34 | 6 | 4.95 |
| F5500 FS | 6.18 | 1 | 5.62 | 6 | 5.14 | 8 | 5.40 |
| F5600 FS | 5.42 | 1 | 5.03 | 3 | 5.93 | 5 | 5.57 |
| F5700 FS | 4.67 | 1 | 5.24 | 3 | 5.82 | 2 | 5.34 |

| | |
|---|---|
| **Company's Overall Mean** | **5.23** |
| **Company's Overall Median** | **5.38** |

(5) Planning and Scheduling

## RATING BY CATEGORY
## PLANNING AND SCHEDULING

| | Foreman | | Supervisors and Peers | | Crew Members | | |
|---|---|---|---|---|---|---|---|
| | Mean | # of participants | Mean | # of participants | Mean | # of participants | Overall Mean |
| **Foreman Code** | | | | | | | |
| F1200 MY | 1.55 | 1 | 3.88 | 2 | 4.38 | 9 | 4.06 |
| F1300 MY | 5.33 | 1 | 4.39 | 4 | 5.23 | 16 | 5.07 |
| F1400 MY | 5.00 | 1 | 5.06 | 6 | 5.73 | 5 | 5.33 |
| F1500 MY | 3.43 | 1 | 4.38 | 6 | 6.15 | 11 | 5.41 |
| F1600 MY | 5.27 | 1 | 4.69 | 5 | 6.10 | 6 | 5.44 |
| F1700 MY | 5.71 | 1 | 5.21 | 5 | 6.06 | 8 | 5.73 |
| F1800 MY | 4.93 | 1 | 5.25 | 2 | 5.77 | 2 | 5.39 |
| F1900 MY | 4.79 | 1 | 5.27 | 3 | 5.01 | 3 | 5.09 |
| F2000 MY | 3.50 | 1 | 4.25 | 4 | 6.15 | 11 | 5.51 |
| F2100 MY | 5.73 | 1 | 5.35 | 5 | 5.49 | 17 | 5.47 |
| F2200 MY | 4.20 | 1 | 4.21 | 4 | 5.08 | 21 | 4.91 |
| F5200 FS | 6.00 | 1 | 6.06 | 4 | 4.79 | 4 | 5.49 |
| F5300 FS | 5.50 | 1 | 5.44 | 6 | 5.68 | 6 | 5.56 |
| F5400 FS | 4.62 | 1 | 5.81 | 5 | 3.99 | 6 | 4.80 |
| F5500 FS | 6.69 | 1 | 5.16 | 6 | 5.33 | 8 | 5.35 |
| F5600 FS | 6.00 | 1 | 5.01 | 3 | 6.03 | 5 | 5.69 |
| F5700 FS | 5.57 | 1 | 5.78 | 3 | 5.72 | 2 | 5.73 |

| | |
|---|---|
| **Company's Overall Mean** | **5.30** |
| **Company's Overall Median** | **5.41** |

(6) Administration

### RATING BY CATEGORY
### ADMINISTRATION

| Foreman Code | Foreman |  | Supervisors and Peers |  | Crew Members |  | Overall Mean |
|---|---|---|---|---|---|---|---|
|  | Mean | # of participants | Mean | # of participants | Mean | # of participants |  |
| F1200 MY | N/A | 1 | 4.00 | 2 | 4.68 | 9 | 4.56 |
| F1300 MY | 4.33 | 1 | 3.97 | 4 | 5.22 | 16 | 4.94 |
| F1400 MY | 5.00 | 1 | 4.63 | 6 | 6.17 | 5 | 5.30 |
| F1500 MY | 2.40 | 1 | 4.11 | 6 | 6.44 | 11 | 5.44 |
| F1600 MY | 5.25 | 1 | 3.89 | 5 | 6.46 | 6 | 5.29 |
| F1700 MY | 5.67 | 1 | 5.00 | 5 | 6.00 | 8 | 5.62 |
| F1800 MY | 5.00 | 1 | 5.00 | 2 | 5.63 | 2 | 5.25 |
| F1900 MY | 4.76 | 1 | 4.97 | 3 | 5.14 | 3 | 5.02 |
| F2000 MY | 4.33 | 1 | 4.75 | 4 | 6.11 | 11 | 5.66 |
| F2100 MY | 4.22 | 1 | 4.17 | 5 | 5.57 | 17 | 5.21 |
| F2200 MY | 4.50 | 1 | 4.22 | 4 | 4.78 | 21 | 4.68 |
| F5200 FS | 6.20 | 1 | 5.93 | 4 | 4.91 | 4 | 5.51 |
| F5300 FS | 5.67 | 1 | 5.78 | 6 | 5.93 | 6 | 5.84 |
| F5400 FS | 4.50 | 1 | 5.83 | 5 | 4.68 | 6 | 5.14 |
| F5500 FS | 6.33 | 1 | 5.29 | 6 | 5.56 | 8 | 5.50 |
| F5600 FS | 5.50 | 1 | 5.02 | 3 | 5.82 | 5 | 5.52 |
| F5700 FS | 5.2 | 1 | 5.26 | 3 | 6.00 | 2 | 5.50 |

|  |  |
|---|---|
| **Company's Overall Mean** | **5.29** |
| **Company's Overall Median** | **5.30** |

## Appendix E: Questionnaires and Re-grouped Questions by Criteria

1) Safety Category

| Question Code | Safety |
|---|---|
| | |
| **S1** | Have a good understanding of HSE good practices and procedures? |
| **S2** | Are knowledgeable in Workers' Compensation Board and insurance provisions? |
| **S3** | Support the company safety program? |
| **S4** | Emphasize safe work practices? |
| **S5** | Communicate safety policies and procedures? |
| **S6** | Complete initial safety and hazard assessments (e.g., FLRAs)? |
| **S7** | Develop safe work plans for your crew members? |
| **S8** | Correctly answer technical safety questions from your crew? |
| **S9** | Conduct safety tool box meetings? |
| **S10** | Identify and arrange for crew safety training? |
| **S11** | Participate in safety/incident investigations and reviews? |
| **S12** | Complete your incident and other safety reports? |
| **S13** | Enforce the company drug and alcohol policy? |

HSE=Health, Safety, and Environmental
FLRA=Field Level Risk Assessment

| Re-grouped Questions Code | Criteria |
|---|---|
| | |
| S1,S2 | Technical knowledge |
| | |
| S3,S4,S5,S13 | Company policies |
| | |
| S6,S11,S12 | Safety procedures |
| | |
| S7,S8,S9,S10 | Safety development by crew |

2) QA/QC Category

| Question Code | QA/QC |
|---|---|
| | |
| **Q1** | Understand the company's QA/QC expectations? |
| **Q2** | Effectively resolve technical and QA/QC issues? |
| **Q3** | Ensure that the crew is working according to the company's QA/QC specifications? |
| **Q4** | Ensure that the crew is working according to job specifications and blueprints? |
| **Q5** | Ensure that the correct tools and equipment are utilized? |
| **Q6** | Inspect the completed work and initiate corrective action if needed? |

QA=Quality Assurance
QC=Quality Control

| Re-grouped Questions Code | Criteria |
|---|---|
| | |
| Q1,Q2 | Inspection and resolve QA/QC problems |
| | |
| Q3,Q4,Q5,Q6 | QA/QC specifications |

### 3) Leadership and Supervision by Category

| Question Code | Leadership and Supervision |
|---|---|
| | |
| L1 | Have good oral communications skills? |
| L2 | Have good written communication skills? |
| L3 | Are punctual and consistently present at work? |
| L4 | Promote pride in workmanship? |
| L5 | Are knowledgeable of your trade's scope of work? |
| L6 | Are knowledgeable of other trades' scope of work? |
| L7 | Are skilled at reading and applying blueprints and specifications? |
| L8 | Are responsible and reliable? |
| L9 | Have good work ethics, integrity, and honesty? |
| L10 | Are able to make good decisions on time? |
| L11 | Are able to adapt to change and be flexible? |
| L12 | Set a good example of behavior and work standards to help ensure crew morale and productivity? |
| L13 | Work in a group or as part of a team? |
| L14 | Assess the capabilities and interests of your crew members? |
| L15 | Match task assignments to your individual crew members' capabilities and interests? |
| L16 | Explain to your crew their responsibilities and duties? |
| L17 | Anticipate and avoid problems? |
| L18 | Promote teamwork and harmony between all construction crews and trades? |
| L19 | Ensure that new crew members are oriented to the job? |
| L20 | Coordinate on the job training for apprentices and facilitate mentoring of apprentices by journeymen? |

| Re-grouped Questions Code | Criteria |
|---|---|
| | |
| L1,L2 | Oral and written communication skills |
| | |
| L5,L6,L7,L14,L15,L16 | Knowledge of crew and scope of work |
| | |
| L3,L4,L8,L9,L12 | Responsibility at work and work ethic |
| | |
| L10,L11,L17 | Decision making abilities |
| | |
| L13,L18,L19,L20 | Team work |

4) Employee Relations Category

| Question Code | Employee Relations |
|---|---|
| | |
| E1 | Respect your crew members? |
| E2 | Consult with and include your crew members in discussions on how to carry out the work? |
| E3 | Coordinate and communicate with other trades? |
| E4 | Recognize, address, and resolve issues/problems within your crew or between crews? |
| E5 | Identify training needs for your crew and facilitate delivery of the training and mentoring programs? |
| E6 | Ensure a respectful and inclusive employee relations work environment? |
| E7 | Know/understand, communicate, and ensure compliance with the company's employee relations policies? |
| E8 | Ensure that the Project Employee Relations Manager or designate is included in all major potentially controversial or questionable employee relations matters, and that his/her advice is applied consistently and fairly? |
| E9 | Document performance problems of crew members? |
| E10 | Investigate and document incidents with crew members accurately and thoroughly? |
| E11 | Apply the company's corrective action policy where applicable? |
| E12 | Apply project procedures, worksite policies, and collective agreement requirements? |

| Re-grouped Questions Code | Criteria |
|---|---|
| | |
| E1,E2,E3,E4,E5 | Crew Issues |
| | |
| E9,E10,E11 | Disciplinary Action |
| | |
| E6,E7,E8,E12 | Company Policies |

5) Planning and Scheduling Category

| Question Code | Planning and Scheduling |
|---|---|
| | |
| **P1** | Understand and apply project schedules? |
| **P2** | Identify needs and deficiencies in the plan/schedule and communicate them to the right person? |
| **P3** | Participates in preparing weekly and look-ahead schedules? |
| **P4** | Translate work requirements into a plan for individual tasks, and assign them to crew members (delegate)? |
| **P5** | Communicate the plan, schedule, and scope of work to your crew members? |
| **P6** | Plan manpower requirements? |
| **P7** | Plan scaffold requirements? |
| **P8** | Plan ahead your work to minimize delays in schedule? |
| **P9** | Identify/verify that all tools and materials (FIWPs) are available and complete? |
| **P10** | Review/adjust specific workface activities and task schedules to meet established production schedules? |
| **P11** | Work with the crew to overcome work challenges? |
| **P12** | Work towards meeting weekly schedule/production targets? |
| **P13** | Work towards meeting weekly productivity targets (e.g., Performance Factors)? |
| **P14** | Identify and attempt to resolve road blocks to productivity? |
| **P15** | Resolve, or else report, schedule problems or conflicts with other crews or contractors? |

FIWP=Field Installation Work Package

| Re-grouped Questions Code | Criteria |
|---|---|
| | |
| P10,P12,P13,P14 | Meeting weekly targets/productivity |
| | |
| P5,P11,P15 | Communication to crew members/other crews |
| | |
| P1,P2,P3 | Planning abilities |
| | |
| P4,P6,P7,P8,P9 | Workface/detailed Planning |

6) Administration Category

| Question Code | Administration |
|---|---|
| | |
| A1 | Keep and update logs or diaries as required? |
| A2 | Maintain accurate time cards? |
| A3 | Report the workface production and work progress? |
| A4 | Complete quality reports? |
| A5 | Complete the statistics required by the company? |
| A6 | Complete your reports in a clear and easy to understand manner? |
| A7 | Requisition supplies on time to address deficiencies in tools and materials (i.e., FIWPs)? |
| A8 | Obtain permits on time? |
| A9 | Distribute cheques and effectively handle problems with cheques? |
| A10 | Recommend personnel actions (e.g. hiring, promotions, discipline)? |
| A11 | Use computers, if required? |

FIWP=Field Installation Work Package

| Re-grouped Questions Code | Criteria |
|---|---|
| | |
| A1,A2,A3,A4,A5 | Documentation |
| | |
| A6,A10,A11 | Communication Skills |
| | |
| A7,A8,A9 | Logistics |

## Appendix F: Responses by Group Assessment Re-Grouped by Variable

1) Foreman (Self-Evaluation)

SAFETY CATEGORY

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 |
|---|---|---|---|---|
| F1200 MY | 3.00 | 5.50 | 5.33 | 5.00 |
| F1300 MY | 4.00 | 4.75 | 4.33 | 4.25 |
| F1400 MY | 5.00 | 5.25 | 4.33 | 5.25 |
| F1500 MY | 4.00 | 6.67 | 7.00 | 6.33 |
| F1600 MY | 3.50 | 4.50 | 7.00 | 5.33 |
| F1700 MY | 5.50 | 6.00 | 6.00 | 5.25 |
| F1800 MY | 5.00 | 6.25 | 5.33 | 5.75 |
| F1900 MY | 2.00 | 5.50 | 3.00 | 4.75 |
| F2000 MY | 3.50 | 5.00 | 3.67 | 3.75 |
| F2100 MY | 5.50 | 6.00 | 6.67 | 4.00 |
| F2200 MY | 4.00 | 5.67 | 5.00 | 4.75 |
| F5200 FS | 6.00 | 6.75 | 6.33 | 6.25 |
| F5300 FS | 4.50 | 6.25 | 6.00 | 5.50 |
| F5400 FS | 4.00 | 5.50 | 5.00 | 5.25 |
| F5500 FS | 4.50 | 6.00 | 6.00 | 6.00 |
| F5600 FS | 4.50 | 6.50 | 3.67 | 6.00 |
| F5700 FS | 4.50 | 5.75 | 7.00 | 5.67 |

## QA/QC

| Foreman Code | Input Variable 1 | Input variable 2 |
|---|---|---|
| F1200 MY | 4.00 | 4.00 |
| F1300 MY | 4.50 | 5.00 |
| F1400 MY | 4.00 | 4.75 |
| F1500 MY | 4.00 | 4.25 |
| F1600 MY | 4.00 | 5.00 |
| F1700 MY | 6.00 | 6.00 |
| F1800 MY | 5.00 | 5.50 |
| F1900 MY | 4.00 | 6.25 |
| F2000 MY | 4.50 | 4.50 |
| F2100 MY | 5.50 | 6.50 |
| F2200 MY | 4.00 | 4.75 |
| F5200 FS | 7.00 | 6.00 |
| F5300 FS | 7.00 | 6.50 |
| F5400 FS | 6.00 | 5.75 |
| F5500 FS | 6.00 | 6.00 |
| F5600 FS | 6.00 | 5.75 |
| F5700 FS | 5.00 | 6.00 |

## LEADERSHIP AND SUPERVISION

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 | Input Variable 5 |
|---|---|---|---|---|---|
| F1200 MY | 2.00 | 4.50 | 5.60 | 5.33 | 5.25 |
| F1300 MY | 5.00 | 4.50 | 4.60 | 4.00 | 4.75 |
| F1400 MY | 4.00 | 5.33 | 5.40 | 5.33 | 5.00 |
| F1500 MY | 2.50 | 4.67 | 6.00 | 3.00 | 4.50 |
| F1600 MY | 5.00 | 5.33 | 6.20 | 4.33 | 4.00 |
| F1700 MY | 6.00 | 5.50 | 6.00 | 5.67 | 5.50 |
| F1800 MY | 5.00 | 5.67 | 6.40 | 5.00 | 5.50 |
| F1900 MY | 4.00 | 5.17 | 6.20 | 5.67 | 5.25 |
| F2000 MY | 3.50 | 5.00 | 5.20 | 4.33 | 4.25 |
| F2100 MY | 6.00 | 6.17 | 6.40 | 5.33 | 4.67 |
| F2200 MY | 5.00 | 5.50 | 5.80 | 5.33 | 4.75 |
| F5200 FS | 6.00 | 6.20 | 7.00 | 6.33 | 6.33 |
| F5300 FS | 6.00 | 6.33 | 6.20 | 6.00 | 5.25 |
| F5400 FS | 3.50 | 4.83 | 4.60 | 4.33 | 4.50 |
| F5500 FS | 5.50 | 6.33 | 7.00 | 7.00 | 6.67 |
| F5600 FS | 5.00 | 5.33 | 7.00 | 5.67 | 6.25 |
| F5700 FS | 5.00 | 5.67 | 6.40 | 5.67 | 5.67 |

## EMPLOYEE RELATIONS

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 |
|---|---|---|---|
| F1200 MY | 4.00 | 4.00 | 3.33 |
| F1300 MY | 4.20 | 4.00 | 4.33 |
| F1400 MY | 4.40 | 4.00 | 4.33 |
| F1500 MY | 5.20 | 4.33 | 2.00 |
| F1600 MY | 5.50 | 3.75 | 3.00 |
| F1700 MY | 4.80 | 6.00 | 5.00 |
| F1800 MY | 5.60 | 5.50 | 4.67 |
| F1900 MY | 4.80 | 4.00 | 4.00 |
| F2000 MY | 4.60 | 3.75 | 4.67 |
| F2100 MY | 4.25 | 4.00 | 6.00 |
| F2200 MY | 5.00 | 4.67 | 4.00 |
| F5200 FS | 6.40 | 6.25 | 6.00 |
| F5300 FS | 5.60 | 5.50 | 5.00 |
| F5400 FS | 5.00 | 4.25 | 4.33 |
| F5500 FS | 6.60 | 6.00 | 5.67 |
| F5600 FS | 5.80 | 5.50 | 4.67 |
| F5700 FS | 4.75 | 5.00 | 4.00 |

## PLANNING AND SCHEDULING

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 |
|---|---|---|---|---|
| F1200 MY | 2.67 | 1.20 | 1.00 | 1.00 |
| F1300 MY | 4.67 | 5.00 | 5.67 | 6.00 |
| F1400 MY | 5.00 | 5.00 | 5.00 | 5.00 |
| F1500 MY | 2.00 | 3.75 | 4.00 | 3.75 |
| F1600 MY | 6.33 | 4.80 | 5.00 | 5.25 |
| F1700 MY | 6.00 | 5.60 | 5.67 | 5.75 |
| F1800 MY | 4.33 | 5.00 | 5.00 | 5.25 |
| F1900 MY | 4.50 | 4.80 | 5.00 | 4.75 |
| F2000 MY | 3.00 | 3.50 | 3.67 | 4.00 |
| F2100 MY | 5.67 | 5.80 | 5.33 | 6.00 |
| F2200 MY | 5.00 | 4.00 | 4.00 | 4.00 |
| F5200 FS | N/A | 6.00 | 6.00 | 6.00 |
| F5300 FS | 5.33 | 5.20 | 6.00 | 5.75 |
| F5400 FS | 4.67 | 4.67 | 5.00 | 4.25 |
| F5500 FS | 6.50 | 6.25 | 7.00 | 7.00 |
| F5600 FS | 6.00 | 5.33 | 6.50 | 6.25 |
| F5700 FS | 5.33 | 5.25 | 5.67 | 6.00 |

## ADMINISTRATION

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 |
|---|---|---|---|
| F1200 MY | N/A | N/A | N/A |
| F1300 MY | 5.00 | 4.00 | N/A |
| F1400 MY | 5.00 | N/A | N/A |
| F1500 MY | 2.50 | 2.66 | 2.00 |
| F1600 MY | 5.00 | 4.00 | 7.00 |
| F1700 MY | 5.67 | 6.00 | 5.50 |
| F1800 MY | 5.50 | 4.50 | 5.00 |
| F1900 MY | 5.00 | 4.50 | 4.50 |
| F2000 MY | 4.50 | 4.00 | N/A |
| F2100 MY | 4.20 | 4.00 | 5.33 |
| F2200 MY | 4.00 | 5.00 | N/A |
| F5200 FS | 6.50 | 6.00 | 6.00 |
| F5300 FS | 5.33 | 6.00 | 6.00 |
| F5400 FS | 4.75 | 4.00 | 4.50 |
| F5500 FS | 6.00 | 7.00 | 6.00 |
| F5600 FS | 5.00 | 6.00 | 5.50 |
| F5700 FS | 5.50 | 5.00 | 5.00 |

2) Supervisors and Peers

SAFETY CATEGORY

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 |
|---|---|---|---|---|
| F1200 MY | 3.25 | 3.63 | 2.50 | 3.00 |
| F1300 MY | 4.38 | 4.90 | 4.89 | 4.63 |
| F1400 MY | 5.15 | 5.24 | 5.52 | 5.20 |
| F1500 MY | 4.38 | 5.21 | 5.50 | 4.96 |
| F1600 MY | 4.30 | 4.23 | 5.07 | 4.95 |
| F1700 MY | 4.96 | 5.78 | 5.67 | 5.63 |
| F1800 MY | 5.50 | 5.88 | 6.17 | 5.63 |
| F1900 MY | 5.17 | 6.08 | 6.00 | 5.50 |
| F2000 MY | 3.88 | 5.06 | 4.75 | 4.88 |
| F2100 MY | 5.38 | 5.38 | 6.53 | 5.88 |
| F2200 MY | 3.71 | 5.04 | 5.17 | 4.44 |
| F5200 FS | 4.88 | 5.50 | 5.53 | 5.00 |
| F5300 FS | 5.52 | 5.56 | 5.53 | 5.20 |
| F5400 FS | 5.60 | 5.90 | 5.73 | 5.73 |
| F5500 FS | 5.60 | 5.83 | 6.06 | 5.71 |
| F5600 FS | 5.00 | 5.38 | 4.89 | 5.54 |
| F5700 FS | 5.00 | 6.08 | 4.67 | 4.96 |

## QA/QC

| Foreman Code | Input Variable 1 | Input variable 2 |
|---|---|---|
| F1200 MY | 3.00 | 3.38 |
| F1300 MY | 4.58 | 4.25 |
| F1400 MY | 5.50 | 5.40 |
| F1500 MY | 4.88 | 5.00 |
| F1600 MY | 4.38 | 4.69 |
| F1700 MY | 5.13 | 5.29 |
| F1800 MY | 5.50 | 5.67 |
| F1900 MY | 5.75 | 6.25 |
| F2000 MY | N/A | N/A |
| F2100 MY | 5.00 | 4.95 |
| F2200 MY | 4.33 | 4.58 |
| F5200 FS | 6.00 | 5.75 |
| F5300 FS | 6.10 | 5.69 |
| F5400 FS | 5.25 | 5.56 |
| F5500 FS | 5.70 | 5.51 |
| F5600 FS | 5.50 | 5.17 |
| F5700 FS | 5.17 | 5.50 |

## LEADERSHIP AND SUPERVISION

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 | Input Variable 5 |
|---|---|---|---|---|---|
| F1200 MY | 2.75 | 4.40 | 5.00 | 4.50 | 4.25 |
| F1300 MY | 3.92 | 4.28 | 5.33 | 4.11 | 4.42 |
| F1400 MY | 3.75 | 4.81 | 4.35 | 5.18 | 3.79 |
| F1500 MY | 4.00 | 4.72 | 5.53 | 4.67 | 4.58 |
| F1600 MY | 4.83 | 4.78 | 5.15 | 5.08 | 4.73 |
| F1700 MY | 5.83 | 5.57 | 6.52 | 5.22 | 5.33 |
| F1800 MY | 6.00 | 6.20 | 7.00 | 6.00 | 6.50 |
| F1900 MY | 5.25 | 5.67 | 6.10 | 4.83 | 5.63 |
| F2000 MY | 4.67 | 4.78 | 5.53 | 4.67 | 4.83 |
| F2100 MY | 5.60 | 5.41 | 5.71 | 5.72 | 5.51 |
| F2200 MY | 4.00 | 4.64 | 5.07 | 4.44 | 4.54 |
| F5200 FS | 5.50 | 5.94 | 6.27 | 5.89 | 5.33 |
| F5300 FS | 5.50 | 5.50 | 5.80 | 5.80 | 5.38 |
| F5400 FS | 5.38 | 6.00 | 5.23 | 5.75 | 5.73 |
| F5500 FS | 5.55 | 6.03 | 5.84 | 5.47 | 5.70 |
| F5600 FS | 4.50 | 5.17 | 5.47 | 4.67 | 5.75 |
| F5700 FS | 5.33 | 5.47 | 6.00 | 5.56 | 6.08 |

## EMPLOYEE RELATIONS

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 |
|---|---|---|---|
| F1200 MY | 2.75 | 4.40 | 5.00 |
| F1300 MY | 3.92 | 4.28 | 5.33 |
| F1400 MY | 3.75 | 4.81 | 4.35 |
| F1500 MY | 4.00 | 4.72 | 5.53 |
| F1600 MY | 4.83 | 4.78 | 5.15 |
| F1700 MY | 5.83 | 5.57 | 6.52 |
| F1800 MY | 6.00 | 6.20 | 7.00 |
| F1900 MY | 5.25 | 5.67 | 6.10 |
| F2000 MY | 4.67 | 4.78 | 5.53 |
| F2100 MY | 5.60 | 5.41 | 5.71 |
| F2200 MY | 4.00 | 4.64 | 5.07 |
| F5200 FS | 5.50 | 5.94 | 6.27 |
| F5300 FS | 5.50 | 5.50 | 5.80 |
| F5400 FS | 5.38 | 6.00 | 5.23 |
| F5500 FS | 5.55 | 6.03 | 5.84 |
| F5600 FS | 4.50 | 5.17 | 5.47 |
| F5700 FS | 5.33 | 5.47 | 6.00 |

## PLANNING AND SCHEDULING

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 |
|---|---|---|---|---|
| F1200 MY | 3.33 | 4.00 | 4.00 | 3.88 |
| F1300 MY | 4.28 | 4.03 | 4.33 | 4.83 |
| F1400 MY | 4.67 | 5.15 | 4.42 | 4.42 |
| F1500 MY | 4.50 | 4.20 | 4.39 | 4.33 |
| F1600 MY | 4.58 | 4.42 | 4.50 | 4.67 |
| F1700 MY | 4.33 | 4.88 | 5.11 | 4.92 |
| F1800 MY | 4.00 | 5.50 | 5.67 | 5.33 |
| F1900 MY | 4.83 | 5.30 | 5.33 | 5.38 |
| F2000 MY | 4.00 | 4.21 | 4.33 | 3.83 |
| F2100 MY | 5.50 | 5.33 | 5.31 | 5.67 |
| F2200 MY | 4.22 | 4.20 | 4.50 | 4.13 |
| F5200 FS | 6.39 | 5.71 | 6.28 | 6.00 |
| F5300 FS | 5.38 | 4.72 | 5.28 | 5.58 |
| F5400 FS | 5.56 | 5.55 | 5.92 | 5.88 |
| F5500 FS | 5.42 | 5.03 | 5.20 | 5.10 |
| F5600 FS | 5.50 | 5.47 | 5.00 | 4.92 |
| F5700 FS | 5.78 | 5.37 | 5.44 | 5.83 |

## ADMINISTRATION

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 |
|---|---|---|---|
| F1200 MY | 4.00 | N/A | 4.00 |
| F1300 MY | 4.20 | N/A | 4.50 |
| F1400 MY | 5.13 | 4.00 | 4.22 |
| F1500 MY | 4.17 | 4.00 | 5.00 |
| F1600 MY | 3.88 | 4.00 | 4.00 |
| F1700 MY | 4.83 | 5.00 | 5.00 |
| F1800 MY | 5.00 | 4.00 | 5.33 |
| F1900 MY | 5.20 | 5.50 | 4.67 |
| F2000 MY | 4.75 | N/A | 4.75 |
| F2100 MY | 3.10 | 2.33 | 3.33 |
| F2200 MY | 4.33 | 3.75 | 4.00 |
| F5200 FS | 5.97 | 5.33 | 5.56 |
| F5300 FS | 5.50 | 4.78 | 5.97 |
| F5400 FS | 5.70 | 6.00 | 5.83 |
| F5500 FS | 5.02 | 4.64 | 4.83 |
| F5600 FS | 5.23 | 5.22 | 5.50 |
| F5700 FS | 5.97 | 5.50 | 5.28 |

3) Crew Members

| | SAFETY CATEGORY | | | |
|---|---|---|---|---|
| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 |
| F1200 MY | 4.43 | 4.69 | 5.16 | 4.85 |
| F1300 MY | 5.12 | 5.69 | 5.37 | 5.46 |
| F1400 MY | 5.03 | 5.65 | 5.98 | 5.63 |
| F1500 MY | 5.93 | 6.44 | 6.48 | 6.37 |
| F1600 MY | 5.92 | 6.58 | 6.69 | 6.28 |
| F1700 MY | 5.50 | 5.76 | 5.56 | 5.71 |
| F1800 MY | 4.50 | 5.50 | 6.83 | 5.88 |
| F1900 MY | 4.50 | 4.83 | 5.28 | 5.21 |
| F2000 MY | 6.24 | 6.24 | 6.43 | 5.85 |
| F2100 MY | 5.04 | 5.74 | 5.61 | 5.51 |
| F2200 MY | 4.79 | 5.17 | 4.80 | 5.02 |
| F5200 FS | 4.38 | 4.60 | 5.06 | 4.67 |
| F5300 FS | 5.80 | 5.75 | 5.92 | 5.52 |
| F5400 FS | 4.92 | 4.75 | 4.92 | 4.13 |
| F5500 FS | 5.67 | 6.01 | 6.00 | 5.69 |
| F5600 FS | 5.50 | 5.65 | 5.90 | 6.30 |
| F5700 FS | 5.25 | 5.63 | 5.67 | 5.75 |

## QA/QC

| Foreman Code | Input Variable 1 | Input variable 2 |
|---|---|---|
| F1200 MY | 4.81 | 4.59 |
| F1300 MY | 5.22 | 5.71 |
| F1400 MY | 4.88 | 5.20 |
| F1500 MY | 6.14 | 6.26 |
| F1600 MY | 6.38 | 6.55 |
| F1700 MY | 6.06 | 6.34 |
| F1800 MY | 4.50 | 5.63 |
| F1900 MY | 5.83 | 6.17 |
| F2000 MY | 6.00 | 6.47 |
| F2100 MY | 5.45 | 5.78 |
| F2200 MY | 4.93 | 5.46 |
| F5200 FS | 4.63 | 5.31 |
| F5300 FS | 6.00 | 5.63 |
| F5400 FS | 5.10 | 4.14 |
| F5500 FS | 5.65 | 5.03 |
| F5600 FS | 5.80 | 5.70 |
| F5700 FS | 6.00 | 6.00 |

## LEADERSHIP AND SUPERVISION

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 | Input Variable 5 |
|---|---|---|---|---|---|
| F1200 MY | 3.99 | 4.18 | 5.58 | 4.47 | 4.55 |
| F1300 MY | 5.26 | 5.37 | 5.57 | 5.15 | 5.55 |
| F1400 MY | 4.77 | 5.12 | 4.56 | 5.33 | 5.38 |
| F1500 MY | 6.09 | 6.33 | 6.35 | 6.17 | 6.42 |
| F1600 MY | 6.00 | 6.36 | 6.53 | 6.02 | 6.13 |
| F1700 MY | 6.06 | 6.11 | 6.28 | 6.08 | 6.02 |
| F1800 MY | 5.25 | 5.42 | 6.30 | 5.67 | 5.75 |
| F1900 MY | 4.83 | 5.89 | 5.93 | 5.22 | 4.75 |
| F2000 MY | 6.31 | 5.95 | 6.27 | 6.29 | 6.21 |
| F2100 MY | 5.06 | 5.38 | 5.77 | 5.48 | 5.28 |
| F2200 MY | 4.90 | 5.06 | 5.31 | 4.91 | 5.01 |
| F5200 FS | 4.88 | 5.01 | 5.35 | 4.92 | 4.46 |
| F5300 FS | 6.00 | 6.01 | 6.25 | 5.68 | 6.23 |
| F5400 FS | 5.08 | 4.48 | 3.25 | 3.78 | 4.35 |
| F5500 FS | 5.80 | 5.65 | 5.76 | 5.13 | 4.89 |
| F5600 FS | 6.23 | 6.13 | 6.12 | 5.87 | 6.00 |
| F5700 FS | 5.75 | 5.67 | 6.00 | 5.50 | 5.88 |

## EMPLOYEE RELATIONS

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 |
|---|---|---|---|
| F1200 MY | 4.22 | 4.21 | 3.48 |
| F1300 MY | 5.33 | 5.13 | 4.92 |
| F1400 MY | 4.86 | 5.04 | 5.50 |
| F1500 MY | 6.50 | 6.30 | 5.89 |
| F1600 MY | 6.08 | 6.12 | 6.89 |
| F1700 MY | 5.98 | 5.88 | 5.33 |
| F1800 MY | 5.70 | 5.75 | 5.67 |
| F1900 MY | 4.67 | 4.88 | 4.33 |
| F2000 MY | 6.34 | 5.99 | 6.37 |
| F2100 MY | 5.49 | 5.46 | 5.39 |
| F2200 MY | 5.18 | 4.94 | 4.77 |
| F5200 FS | 4.65 | 4.00 | 4.22 |
| F5300 FS | 5.95 | 5.78 | 5.42 |
| F5400 FS | 4.33 | 4.81 | 5.61 |
| F5500 FS | 5.12 | 4.85 | 5.10 |
| F5600 FS | 6.00 | 6.04 | 6.19 |
| F5700 FS | 5.80 | 5.63 | 6.17 |

## PLANNING AND SCHEDULING

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 | Input Variable 4 |
|---|---|---|---|---|
| F1200 MY | 4.07 | 4.44 | 4.13 | 4.33 |
| F1300 MY | 5.15 | 5.27 | 5.30 | 5.19 |
| F1400 MY | 5.77 | 6.02 | 5.47 | 5.49 |
| F1500 MY | 6.00 | 6.33 | 6.48 | 6.43 |
| F1600 MY | 6.33 | 5.91 | 6.11 | 6.17 |
| F1700 MY | 6.01 | 6.07 | 6.21 | 6.03 |
| F1800 MY | 5.67 | 5.88 | 5.83 | 5.63 |
| F1900 MY | 5.17 | 5.00 | 5.11 | 4.92 |
| F2000 MY | 5.90 | 6.10 | 6.32 | 6.03 |
| F2100 MY | 5.47 | 5.54 | 5.43 | 5.59 |
| F2200 MY | 5.14 | 4.95 | 5.11 | 5.00 |
| F5200 FS | 4.61 | 4.45 | 4.69 | 5.04 |
| F5300 FS | 6.08 | 5.70 | 5.57 | 5.73 |
| F5400 FS | 4.33 | 3.88 | 4.36 | 3.86 |
| F5500 FS | 5.41 | 5.18 | 5.33 | 5.27 |
| F5600 FS | 6.42 | 5.75 | 6.13 | 6.19 |
| F5700 FS | 5.67 | 5.60 | 5.83 | 5.75 |

## ADMINISTRATION

| Foreman Code | Input Variable 1 | Input Variable 2 | Input Variable 3 |
|---|---|---|---|
| F1200 MY | 5.37 | 4.48 | 4.11 |
| F1300 MY | 5.25 | 5.28 | 5.02 |
| F1400 MY | 6.08 | 6.00 | 5.50 |
| F1500 MY | 6.39 | 5.74 | 5.00 |
| F1600 MY | 6.81 | 6.67 | 6.25 |
| F1700 MY | 6.21 | 5.64 | 5.61 |
| F1800 MY | 6.00 | 6.00 | 5.00 |
| F1900 MY | 5.07 | 4.78 | 5.17 |
| F2000 MY | 6.16 | 6.33 | 5.67 |
| F2100 MY | 5.63 | 5.50 | 5.88 |
| F2200 MY | 4.83 | 4.87 | 4.54 |
| F5200 FS | 4.85 | 4.33 | 4.47 |
| F5300 FS | 6.57 | 6.03 | 6.61 |
| F5400 FS | 4.88 | 4.84 | 4.82 |
| F5500 FS | 5.18 | 4.87 | 5.23 |
| F5600 FS | 6.23 | 6.67 | 6.17 |
| F5700 FS | 6.20 | 5.67 | 6.00 |

## Appendix G: Testing Results Model Validation

1) Safety

| | Safety | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.68 | 5.15 | -9.12 |
| F1300 MY | 5.27 | 5.12 | 3.00 |
| F1400 MY | 5.45 | 5.43 | 0.35 |
| F1500 MY | 5.91 | 6.50 | -9.13 |
| F1600 MY | 5.48 | 5.53 | -0.88 |
| F1700 MY | 5.73 | 5.96 | -3.86 |
| F1800 MY | 5.87 | 6.23 | -5.88 |
| F1900 MY | 5.21 | 5.40 | -3.54 |
| F2000 MY | 5.49 | 5.17 | 6.14 |
| F2100 MY | 5.42 | 6.24 | -13.18 |
| F2200 MY | 4.94 | 5.26 | -6.08 |
| F5200 FS | 5.21 | 5.67 | -8.14 |
| F5300 FS | 5.53 | 6.14 | -9.93 |
| F5400 FS | 5.14 | 5.47 | -6.02 |
| F5500 FS | 5.81 | 6.50 | -10.59 |
| F5600 FS | 5.52 | 5.92 | -6.85 |
| F5700 FS | 5.52 | 5.88 | -6.09 |

| | |
|---|---|
| Average % difference | 6.40 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.49 | 4.00 | 12.17 |
| F1300 MY | 5.31 | 5.25 | 1.11 |
| F1400 MY | 5.33 | 5.46 | -2.40 |
| F1500 MY | 5.68 | 5.25 | 8.19 |
| F1600 MY | 5.55 | 5.25 | 5.76 |
| F1700 MY | 5.92 | 6.50 | -8.90 |
| F1800 MY | 5.35 | 5.82 | -8.08 |
| F1900 MY | 6.03 | 6.50 | -7.21 |
| F2000 MY | 6.14 | 6.50 | -5.53 |
| F2100 MY | 5.52 | 6.05 | -8.79 |
| F2200 MY | 5.13 | 5.07 | 1.19 |
| F5200 FS | 5.54 | 6.50 | -14.72 |
| F5300 FS | 5.84 | 6.50 | -10.17 |
| F5400 FS | 5.07 | 5.79 | -12.44 |
| F5500 FS | 5.35 | 5.94 | -9.82 |
| F5600 FS | 5.59 | 6.14 | -8.81 |
| F5700 FS | 5.62 | 6.50 | -13.62 |

| | |
|---|---|
| Average % difference | 8.17 |

3) Leadership and Supervision

| | leadership and Supervision | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.71 | 4.80 | -1.79 |
| F1300 MY | 5.19 | 4.94 | 5.07 |
| F1400 MY | 4.92 | 5.33 | -7.75 |
| F1500 MY | 5.67 | 5.00 | 13.38 |
| F1600 MY | 5.62 | 5.25 | 7.00 |
| F1700 MY | 6.03 | 5.97 | 1.00 |
| F1800 MY | 6.00 | 5.88 | 2.01 |
| F1900 MY | 5.51 | 5.52 | -0.22 |
| F2000 MY | 5.82 | 5.10 | 14.15 |
| F2100 MY | 5.46 | 5.82 | -6.11 |
| F2200 MY | 5.02 | 5.26 | -4.48 |
| F5200 FS | 5.61 | 6.25 | -10.25 |
| F5300 FS | 5.88 | 6.50 | -9.61 |
| F5400 FS | 4.75 | 4.79 | -0.91 |
| F5500 FS | 5.68 | 5.98 | -4.90 |
| F5600 FS | 5.72 | 5.88 | -2.74 |
| F5700 FS | 5.72 | 5.88 | -2.69 |

| | |
|---|---|
| Average % difference | 5.53 |

4) Employee Relations

| | Employee Relations | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.22 | 4.01 | 5.20 |
| F1300 MY | 4.90 | 4.39 | 11.64 |
| F1400 MY | 4.56 | 4.61 | -1.08 |
| F1500 MY | 5.77 | 4.16 | 38.63 |
| F1600 MY | 5.39 | 4.84 | 11.54 |
| F1700 MY | 5.47 | 5.25 | 4.13 |
| F1800 MY | 5.73 | 6.04 | -5.07 |
| F1900 MY | 4.92 | 4.94 | -0.33 |
| F2000 MY | 5.68 | 4.87 | 16.77 |
| F2100 MY | 5.38 | 5.80 | -7.21 |
| F2200 MY | 4.83 | 5.03 | -4.03 |
| F5200 FS | 5.21 | 5.63 | -7.62 |
| F5300 FS | 5.60 | 5.67 | -1.20 |
| F5400 FS | 4.95 | 5.12 | -3.38 |
| F5500 FS | 5.40 | 5.83 | -7.42 |
| F5600 FS | 5.57 | 5.79 | -3.82 |
| F5700 FS | 5.34 | 5.64 | -5.28 |

| | |
|---|---|
| Average % difference | 7.90 |

5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.06 | 3.80 | 7.00 |
| F1300 MY | 5.07 | 5.45 | -6.82 |
| F1400 MY | 5.33 | 5.25 | 1.58 |
| F1500 MY | 5.41 | 4.52 | 19.69 |
| F1600 MY | 5.44 | 5.43 | 0.25 |
| F1700 MY | 5.73 | 6.03 | -4.95 |
| F1800 MY | 5.39 | 5.67 | -4.83 |
| F1900 MY | 5.09 | 5.32 | -4.39 |
| F2000 MY | 5.51 | 4.44 | 24.10 |
| F2100 MY | 5.47 | 5.85 | -6.51 |
| F2200 MY | 4.91 | 4.46 | 10.26 |
| F5200 FS | 5.49 | 6.50 | -15.56 |
| F5300 FS | 5.56 | 6.04 | -8.04 |
| F5400 FS | 4.80 | 5.00 | -4.06 |
| F5500 FS | 5.35 | 5.46 | -2.04 |
| F5600 FS | 5.69 | 6.50 | -12.51 |
| F5700 FS | 5.73 | 6.08 | -5.89 |

| | |
|---|---|
| Average % difference | 8.15 |

6) Administration

| | Administration | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.56 | 4.65 | -2.04 |
| F1300 MY | 4.94 | 5.25 | -5.93 |
| F1400 MY | 5.30 | 5.25 | 0.98 |
| F1500 MY | 5.44 | 4.46 | 22.06 |
| F1600 MY | 5.29 | 5.25 | 0.71 |
| F1700 MY | 5.62 | 5.84 | -3.75 |
| F1800 MY | 5.25 | 5.25 | 0.02 |
| F1900 MY | 5.02 | 5.30 | -5.30 |
| F2000 MY | 5.66 | 4.94 | 14.57 |
| F2100 MY | 5.21 | 4.39 | 18.61 |
| F2200 MY | 4.68 | 5.16 | -9.30 |
| F5200 FS | 5.51 | 5.81 | -5.19 |
| F5300 FS | 5.84 | 6.50 | -10.14 |
| F5400 FS | 5.14 | 5.07 | 1.40 |
| F5500 FS | 5.50 | 5.39 | 2.16 |
| F5600 FS | 5.52 | 5.67 | -2.65 |
| F5700 FS | 5.50 | 5.67 | -3.02 |

| | |
|---|---|
| Average % difference | 6.34 |

7) Overall Foreman's Skills Level

| | Overall Performance | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.45 | 4.32 | 2.96 |
| F1300 MY | 5.11 | 5.12 | -0.04 |
| F1400 MY | 5.15 | 5.22 | -1.30 |
| F1500 MY | 5.65 | 4.80 | 17.60 |
| F1600 MY | 5.46 | 6.00 | -8.96 |
| F1700 MY | 5.75 | 5.75 | 0.03 |
| F1800 MY | 5.60 | 5.69 | -1.56 |
| F1900 MY | 5.30 | 5.27 | 0.59 |
| F2000 MY | 5.72 | 5.05 | 13.17 |
| F2100 MY | 5.41 | 5.59 | -3.26 |
| F2200 MY | 4.92 | 5.07 | -3.06 |
| F5200 FS | 5.43 | 5.90 | -7.98 |
| F5300 FS | 5.71 | 6.25 | -8.69 |
| F5400 FS | 4.97 | 5.08 | -2.12 |
| F5500 FS | 5.52 | 5.72 | -3.47 |
| F5600 FS | 5.60 | 5.74 | -2.35 |
| F5700 FS | 5.57 | 5.70 | -2.37 |

| | |
|---|---|
| Average % difference | 4.68 |

## Appendix H: Sensitivity Analysis I Results

1) Safety

| | Safety | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.68 | 5.21 | -10.16 |
| F1300 MY | 5.27 | 5.21 | 1.23 |
| F1400 MY | 5.45 | 5.55 | -1.82 |
| F1500 MY | 5.91 | 7.00 | -15.62 |
| F1600 MY | 5.48 | 5.71 | -4.05 |
| F1700 MY | 5.73 | 6.23 | -8.05 |
| F1800 MY | 5.87 | 6.64 | -11.66 |
| F1900 MY | 5.21 | 5.52 | -5.62 |
| F2000 MY | 5.49 | 5.15 | 6.50 |
| F2100 MY | 5.42 | 6.65 | -18.56 |
| F2200 MY | 4.94 | 5.35 | -7.64 |
| F5200 FS | 5.21 | 5.96 | -12.62 |
| F5300 FS | 5.53 | 6.40 | -13.54 |
| F5400 FS | 5.14 | 5.58 | -7.85 |
| F5500 FS | 5.81 | 7.00 | -16.98 |
| F5600 FS | 5.52 | 6.42 | -14.07 |
| F5700 FS | 5.52 | 6.15 | -10.21 |

| | |
|---|---|
| Average % difference | 9.77 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.49 | 4.00 | 12.17 |
| F1300 MY | 5.31 | 5.35 | -0.81 |
| F1400 MY | 5.33 | 5.50 | -3.14 |
| F1500 MY | 5.68 | 5.20 | 9.23 |
| F1600 MY | 5.55 | 5.20 | 6.78 |
| F1700 MY | 5.92 | 7.00 | -15.41 |
| F1800 MY | 5.35 | 6.19 | -13.50 |
| F1900 MY | 6.03 | 7.00 | -13.84 |
| F2000 MY | 6.14 | 7.00 | -12.27 |
| F2100 MY | 5.52 | 6.44 | -14.38 |
| F2200 MY | 5.13 | 5.02 | 2.23 |
| F5200 FS | 5.54 | 7.00 | -20.81 |
| F5300 FS | 5.84 | 7.00 | -16.58 |
| F5400 FS | 5.07 | 5.96 | -15.05 |
| F5500 FS | 5.35 | 6.29 | -14.91 |
| F5600 FS | 5.59 | 6.42 | -12.83 |
| F5700 FS | 5.62 | 7.00 | -19.79 |

| | |
|---|---|
| Average % difference | 11.98 |

### 3) Leadership and Supervision

| | leadership and Supervision | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.71 | 4.82 | -2.20 |
| F1300 MY | 5.19 | 4.97 | 4.43 |
| F1400 MY | 4.92 | 5.43 | -9.45 |
| F1500 MY | 5.67 | 4.93 | 15.14 |
| F1600 MY | 5.62 | 5.29 | 6.24 |
| F1700 MY | 6.03 | 6.13 | -1.73 |
| F1800 MY | 6.00 | 6.15 | -2.46 |
| F1900 MY | 5.51 | 5.56 | -0.89 |
| F2000 MY | 5.82 | 5.18 | 12.25 |
| F2100 MY | 5.46 | 6.04 | -9.65 |
| F2200 MY | 5.02 | 5.31 | -5.37 |
| F5200 FS | 5.61 | 6.67 | -15.83 |
| F5300 FS | 5.88 | 7.00 | -16.07 |
| F5400 FS | 4.75 | 4.87 | -2.46 |
| F5500 FS | 5.68 | 6.23 | -8.80 |
| F5600 FS | 5.72 | 6.15 | -6.96 |
| F5700 FS | 5.72 | 6.19 | -7.51 |

| | |
|---|---|
| Average % difference | 7.50 |

### 4) Employee Relations

| | Employee Relations | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.22 | 4.01 | 5.16 |
| F1300 MY | 4.90 | 4.40 | 11.43 |
| F1400 MY | 4.56 | 4.57 | -0.22 |
| F1500 MY | 5.77 | 4.20 | 37.43 |
| F1600 MY | 5.39 | 4.75 | 13.44 |
| F1700 MY | 5.47 | 5.29 | 3.39 |
| F1800 MY | 5.73 | 6.31 | -9.11 |
| F1900 MY | 4.92 | 5.02 | -1.95 |
| F2000 MY | 5.68 | 4.94 | 14.92 |
| F2100 MY | 5.38 | 5.90 | -8.72 |
| F2200 MY | 4.83 | 5.06 | -4.61 |
| F5200 FS | 5.21 | 5.46 | -4.58 |
| F5300 FS | 5.60 | 5.86 | -4.43 |
| F5400 FS | 4.95 | 5.06 | -2.13 |
| F5500 FS | 5.40 | 6.06 | -10.91 |
| F5600 FS | 5.57 | 5.89 | -5.35 |
| F5700 FS | 5.34 | 5.95 | -10.26 |

| | |
|---|---|
| Average % difference | 8.71 |

## 5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.06 | 3.76 | 8.13 |
| F1300 MY | 5.07 | 5.58 | -9.02 |
| F1400 MY | 5.33 | 5.32 | 0.24 |
| F1500 MY | 5.41 | 4.49 | 20.36 |
| F1600 MY | 5.44 | 5.58 | -2.46 |
| F1700 MY | 5.73 | 6.34 | -9.63 |
| F1800 MY | 5.39 | 5.88 | -8.22 |
| F1900 MY | 5.09 | 5.42 | -6.03 |
| F2000 MY | 5.51 | 4.38 | 25.90 |
| F2100 MY | 5.47 | 5.97 | -8.32 |
| F2200 MY | 4.91 | 4.45 | 10.50 |
| F5200 FS | 5.49 | 7.00 | -21.59 |
| F5300 FS | 5.56 | 6.24 | -11.03 |
| F5400 FS | 4.80 | 4.93 | -2.62 |
| F5500 FS | 5.35 | 5.63 | -5.00 |
| F5600 FS | 5.69 | 7.00 | -18.76 |
| F5700 FS | 5.73 | 6.31 | -9.25 |

| | |
|---|---|
| Average % difference | 10.41 |

## 6) Administration

| | Administration | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.56 | 4.78 | -4.75 |
| F1300 MY | 4.94 | 5.34 | -7.43 |
| F1400 MY | 5.30 | 5.30 | -0.03 |
| F1500 MY | 5.44 | 4.35 | 25.15 |
| F1600 MY | 5.29 | 5.20 | 1.65 |
| F1700 MY | 5.62 | 6.21 | -9.45 |
| F1800 MY | 5.25 | 5.29 | -0.69 |
| F1900 MY | 5.02 | 5.41 | -7.32 |
| F2000 MY | 5.66 | 4.93 | 14.74 |
| F2100 MY | 5.21 | 4.40 | 18.36 |
| F2200 MY | 4.68 | 5.07 | -7.61 |
| F5200 FS | 5.51 | 6.00 | -8.30 |
| F5300 FS | 5.84 | 7.00 | -16.56 |
| F5400 FS | 5.14 | 5.00 | 2.82 |
| F5500 FS | 5.50 | 5.47 | 0.63 |
| F5600 FS | 5.52 | 5.86 | -5.81 |
| F5700 FS | 5.50 | 5.89 | -6.73 |

| | |
|---|---|
| Average % difference | 8.12 |

7) Overall Foreman's Skills Level

| | Overall Performance | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.45 | 4.28 | 4.02 |
| F1300 MY | 5.11 | 5.18 | -1.30 |
| F1400 MY | 5.15 | 5.24 | -1.82 |
| F1500 MY | 5.65 | 4.82 | 17.18 |
| F1600 MY | 5.46 | 5.23 | 4.45 |
| F1700 MY | 5.75 | 5.93 | -3.10 |
| F1800 MY | 5.60 | 5.87 | -4.64 |
| F1900 MY | 5.30 | 5.30 | -0.03 |
| F2000 MY | 5.72 | 5.11 | 11.80 |
| F2100 MY | 5.41 | 5.76 | -6.13 |
| F2200 MY | 4.92 | 5.10 | -3.46 |
| F5200 FS | 5.43 | 6.12 | -11.36 |
| F5300 FS | 5.71 | 6.60 | -13.53 |
| F5400 FS | 4.97 | 5.14 | -3.18 |
| F5500 FS | 5.52 | 5.87 | -5.98 |
| F5600 FS | 5.60 | 6.03 | -7.14 |
| F5700 FS | 5.57 | 5.89 | -5.48 |

| | |
|---|---|
| Average % difference | 6.15 |

## Appendix I: Sensitivity Analysis II Results

1) Safety

| | Safety | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.68 | 5.06 | -7.47 |
| F1300 MY | 5.27 | 5.08 | 3.81 |
| F1400 MY | 5.45 | 5.34 | 2.07 |
| F1500 MY | 5.91 | 6.50 | -9.13 |
| F1600 MY | 5.48 | 5.45 | 0.45 |
| F1700 MY | 5.73 | 5.91 | -3.12 |
| F1800 MY | 5.87 | 6.23 | -5.87 |
| F1900 MY | 5.21 | 5.32 | -2.07 |
| F2000 MY | 5.49 | 5.03 | 9.06 |
| F2100 MY | 5.42 | 6.22 | -12.91 |
| F2200 MY | 4.94 | 5.16 | -4.30 |
| F5200 FS | 5.21 | 5.63 | -7.55 |
| F5300 FS | 5.53 | 6.05 | -8.47 |
| F5400 FS | 5.14 | 5.39 | -4.60 |
| F5500 FS | 5.81 | 6.50 | -10.59 |
| F5600 FS | 5.52 | 6.00 | -8.10 |
| F5700 FS | 5.52 | 5.85 | -5.60 |

| | |
|---|---|
| Average % difference | 6.19 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.49 | 4.26 | 5.43 |
| F1300 MY | 5.31 | 5.13 | 3.55 |
| F1400 MY | 5.33 | 5.32 | 0.08 |
| F1500 MY | 5.68 | 5.25 | 8.19 |
| F1600 MY | 5.55 | 5.07 | 9.49 |
| F1700 MY | 5.92 | 6.50 | -8.90 |
| F1800 MY | 5.35 | 5.83 | -8.09 |
| F1900 MY | 6.03 | 6.50 | -7.21 |
| F2000 MY | 6.14 | 6.50 | -5.53 |
| F2100 MY | 5.52 | 6.05 | -8.79 |
| F2200 MY | 5.13 | 4.86 | 5.53 |
| F5200 FS | 5.54 | 6.50 | -14.72 |
| F5300 FS | 5.84 | 6.50 | -10.17 |
| F5400 FS | 5.07 | 5.68 | -10.80 |
| F5500 FS | 5.35 | 5.91 | -9.41 |
| F5600 FS | 5.59 | 6.04 | -7.32 |
| F5700 FS | 5.62 | 6.50 | -13.62 |

| | |
|---|---|
| Average % difference | 8.05 |

3) Leadership and Supervision

| | leadership and Supervision | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.71 | 4.68 | 0.64 |
| F1300 MY | 5.19 | 4.86 | 6.81 |
| F1400 MY | 4.92 | 5.22 | -5.83 |
| F1500 MY | 5.67 | 5.15 | 10.14 |
| F1600 MY | 5.62 | 5.16 | 8.81 |
| F1700 MY | 6.03 | 5.84 | 3.26 |
| F1800 MY | 6.00 | 5.85 | 2.55 |
| F1900 MY | 5.51 | 5.35 | 3.06 |
| F2000 MY | 5.82 | 4.98 | 16.68 |
| F2100 MY | 5.46 | 5.75 | -5.11 |
| F2200 MY | 5.02 | 5.12 | -1.98 |
| F5200 FS | 5.61 | 6.25 | -10.19 |
| F5300 FS | 5.88 | 6.50 | -9.61 |
| F5400 FS | 4.75 | 4.72 | 0.50 |
| F5500 FS | 5.68 | 5.86 | -3.01 |
| F5600 FS | 5.72 | 5.82 | -1.68 |
| F5700 FS | 5.72 | 5.88 | -2.67 |

| | |
|---|---|
| Average % difference | 5.44 |

4) Employee Relations

| | Employee Relations | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.22 | 4.01 | 5.25 |
| F1300 MY | 4.90 | 4.37 | 12.22 |
| F1400 MY | 4.56 | 4.52 | 0.88 |
| F1500 MY | 5.77 | 4.16 | 38.63 |
| F1600 MY | 5.39 | 4.68 | 15.15 |
| F1700 MY | 5.47 | 5.07 | 7.77 |
| F1800 MY | 5.73 | 5.97 | -4.02 |
| F1900 MY | 4.92 | 4.87 | 0.98 |
| F2000 MY | 5.68 | 4.85 | 17.11 |
| F2100 MY | 5.38 | 5.65 | -4.69 |
| F2200 MY | 4.83 | 4.91 | -1.59 |
| F5200 FS | 5.21 | 5.47 | -4.76 |
| F5300 FS | 5.60 | 5.62 | -0.31 |
| F5400 FS | 4.95 | 4.95 | 0.02 |
| F5500 FS | 5.40 | 5.72 | -5.55 |
| F5600 FS | 5.57 | 5.64 | -1.18 |
| F5700 FS | 5.34 | 5.63 | -5.25 |

| | |
|---|---|
| Average % error | 7.37 |

5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.06 | 3.80 | 7.00 |
| F1300 MY | 5.07 | 5.35 | -5.23 |
| F1400 MY | 5.33 | 5.16 | 3.31 |
| F1500 MY | 5.41 | 4.95 | 9.27 |
| F1600 MY | 5.44 | 5.39 | 1.00 |
| F1700 MY | 5.73 | 5.95 | -3.70 |
| F1800 MY | 5.39 | 5.63 | -4.21 |
| F1900 MY | 5.09 | 5.22 | -2.44 |
| F2000 MY | 5.51 | 4.34 | 26.81 |
| F2100 MY | 5.47 | 5.70 | -4.09 |
| F2200 MY | 4.91 | 4.41 | 11.47 |
| F5200 FS | 5.49 | 6.50 | -15.56 |
| F5300 FS | 5.56 | 5.92 | -6.22 |
| F5400 FS | 4.80 | 4.84 | -0.77 |
| F5500 FS | 5.35 | 5.42 | -1.31 |
| F5600 FS | 5.69 | 6.50 | -12.51 |
| F5700 FS | 5.73 | 5.97 | -4.17 |

| | |
|---|---|
| Average % difference | 7.00 |

6) Administration

| | Administration | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.56 | 4.65 | -2.04 |
| F1300 MY | 4.94 | 5.11 | -3.38 |
| F1400 MY | 5.30 | 5.16 | 2.79 |
| F1500 MY | 5.44 | 5.12 | 6.13 |
| F1600 MY | 5.29 | 5.07 | 4.25 |
| F1700 MY | 5.62 | 5.84 | -3.75 |
| F1800 MY | 5.25 | 5.07 | 3.52 |
| F1900 MY | 5.02 | 5.19 | -3.42 |
| F2000 MY | 5.66 | 4.78 | 18.45 |
| F2100 MY | 5.21 | 4.33 | 20.23 |
| F2200 MY | 4.68 | 4.96 | -5.56 |
| F5200 FS | 5.51 | 5.74 | -3.99 |
| F5300 FS | 5.84 | 6.50 | -10.14 |
| F5400 FS | 5.14 | 4.88 | 5.39 |
| F5500 FS | 5.50 | 5.27 | 4.47 |
| F5600 FS | 5.52 | 5.62 | -1.76 |
| F5700 FS | 5.50 | 5.64 | -2.62 |

| | |
|---|---|
| Average % difference | 5.99 |

### 7) Overall Foreman's Skills Level

| Foreman Code | Overall Performance | | |
|---|---|---|---|
| | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.45 | 4.29 | 3.73 |
| F1300 MY | 5.11 | 5.06 | 1.05 |
| F1400 MY | 5.15 | 5.11 | 0.77 |
| F1500 MY | 5.65 | 4.73 | 19.37 |
| F1600 MY | 5.46 | 5.11 | 6.87 |
| F1700 MY | 5.75 | 5.68 | 1.19 |
| F1800 MY | 5.60 | 5.66 | -1.02 |
| F1900 MY | 5.30 | 5.18 | 2.16 |
| F2000 MY | 5.72 | 4.99 | 14.59 |
| F2100 MY | 5.41 | 5.56 | -2.73 |
| F2200 MY | 4.92 | 4.99 | -1.45 |
| F5200 FS | 5.43 | 5.85 | -7.15 |
| F5300 FS | 5.71 | 6.23 | -8.35 |
| F5400 FS | 4.97 | 5.01 | -0.64 |
| F5500 FS | 5.52 | 5.64 | -2.17 |
| F5600 FS | 5.60 | 5.73 | -2.32 |
| F5700 FS | 5.57 | 5.64 | -1.27 |

| | |
|---|---|
| Average % difference | 4.52 |

## Appendix J: Sensitivity Analysis III Results

1) Safety

| | Safety | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.68 | 4.85 | -3.43 |
| F1300 MY | 5.27 | 4.85 | 8.68 |
| F1400 MY | 5.45 | 5.61 | -2.95 |
| F1500 MY | 5.91 | 7.00 | -15.62 |
| F1600 MY | 5.48 | 5.97 | -8.27 |
| F1700 MY | 5.73 | 6.77 | -15.45 |
| F1800 MY | 5.87 | 6.97 | -15.83 |
| F1900 MY | 5.21 | 5.54 | -5.97 |
| F2000 MY | 5.49 | 4.75 | 15.52 |
| F2100 MY | 5.42 | 6.97 | -22.27 |
| F2200 MY | 4.94 | 5.16 | -4.13 |
| F5200 FS | 5.21 | 6.44 | -19.21 |
| F5300 FS | 5.53 | 6.89 | -19.65 |
| F5400 FS | 5.14 | 5.68 | -9.52 |
| F5500 FS | 5.81 | 7.00 | -16.98 |
| F5600 FS | 5.52 | 6.98 | -20.96 |
| F5700 FS | 5.52 | 6.70 | -17.58 |

| | |
|---|---|
| Average % difference | 13.06 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.49 | 4.00 | 12.17 |
| F1300 MY | 5.31 | 5.15 | 2.98 |
| F1400 MY | 5.33 | 5.50 | -3.13 |
| F1500 MY | 5.68 | 4.86 | 16.94 |
| F1600 MY | 5.55 | 4.86 | 14.32 |
| F1700 MY | 5.92 | 7.00 | -15.41 |
| F1800 MY | 5.35 | 6.73 | -20.47 |
| F1900 MY | 6.03 | 7.00 | -13.84 |
| F2000 MY | 6.14 | 7.00 | -12.27 |
| F2100 MY | 5.52 | 6.91 | -20.11 |
| F2200 MY | 5.13 | 4.52 | 13.43 |
| F5200 FS | 5.54 | 7.00 | -20.81 |
| F5300 FS | 5.84 | 7.00 | -16.58 |
| F5400 FS | 5.07 | 6.46 | -21.62 |
| F5500 FS | 5.35 | 6.82 | -21.49 |
| F5600 FS | 5.59 | 6.90 | -18.87 |
| F5700 FS | 5.62 | 7.00 | -19.79 |

| | |
|---|---|
| Average % difference | 15.54 |

3) Leadership and Supervision

|  | leadership and Supervision |  |  |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.71 | 4.27 | 10.40 |
| F1300 MY | 5.19 | 4.68 | 10.94 |
| F1400 MY | 4.92 | 5.34 | -7.88 |
| F1500 MY | 5.67 | 4.40 | 29.00 |
| F1600 MY | 5.62 | 5.08 | 10.49 |
| F1700 MY | 6.03 | 6.68 | -9.82 |
| F1800 MY | 6.00 | 6.70 | -10.47 |
| F1900 MY | 5.51 | 5.64 | -2.29 |
| F2000 MY | 5.82 | 4.79 | 21.46 |
| F2100 MY | 5.46 | 6.58 | -16.97 |
| F2200 MY | 5.02 | 5.06 | -0.75 |
| F5200 FS | 5.61 | 6.97 | -19.52 |
| F5300 FS | 5.88 | 7.00 | -16.07 |
| F5400 FS | 4.75 | 4.32 | 9.97 |
| F5500 FS | 5.68 | 6.78 | -16.12 |
| F5600 FS | 5.72 | 6.70 | -14.61 |
| F5700 FS | 5.72 | 6.73 | -15.04 |

| Average % difference | 13.05 |
|---|---|

4) Employee Relations

|  | Employee Relations |  |  |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.22 | 4.01 | 5.13 |
| F1300 MY | 4.90 | 4.01 | 22.12 |
| F1400 MY | 4.56 | 4.11 | 10.98 |
| F1500 MY | 5.77 | 4.02 | 43.40 |
| F1600 MY | 5.39 | 4.22 | 27.73 |
| F1700 MY | 5.47 | 5.02 | 8.85 |
| F1800 MY | 5.73 | 6.83 | -16.04 |
| F1900 MY | 4.92 | 4.56 | 7.91 |
| F2000 MY | 5.68 | 4.41 | 28.89 |
| F2100 MY | 5.38 | 6.34 | -15.13 |
| F2200 MY | 4.83 | 4.58 | 5.45 |
| F5200 FS | 5.21 | 6.00 | -13.20 |
| F5300 FS | 5.60 | 6.29 | -10.93 |
| F5400 FS | 4.95 | 4.59 | 7.84 |
| F5500 FS | 5.40 | 6.60 | -18.16 |
| F5600 FS | 5.57 | 6.34 | -12.03 |
| F5700 FS | 5.34 | 6.42 | -16.86 |

| Average % difference | 15.92 |
|---|---|

## 5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.06 | 5.50 | -26.17 |
| F1300 MY | 5.07 | 5.68 | -10.67 |
| F1400 MY | 5.33 | 5.09 | 4.81 |
| F1500 MY | 5.41 | 4.09 | 32.38 |
| F1600 MY | 5.44 | 5.68 | -4.25 |
| F1700 MY | 5.73 | 6.85 | -16.39 |
| F1800 MY | 5.39 | 5.12 | 5.39 |
| F1900 MY | 5.09 | 5.31 | -4.05 |
| F2000 MY | 5.51 | 4.04 | 36.26 |
| F2100 MY | 5.47 | 6.46 | -15.37 |
| F2200 MY | 4.91 | 4.06 | 20.86 |
| F5200 FS | 5.49 | 7.00 | -21.59 |
| F5300 FS | 5.56 | 6.79 | -18.14 |
| F5400 FS | 4.80 | 4.40 | 9.00 |
| F5500 FS | 5.35 | 5.81 | -7.91 |
| F5600 FS | 5.69 | 7.00 | -18.76 |
| F5700 FS | 5.73 | 6.83 | -16.22 |

| | |
|---|---|
| Average % difference | 15.78 |

## 6) Administration

| | Administration | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.56 | 4.24 | 7.37 |
| F1300 MY | 4.94 | 5.12 | -3.54 |
| F1400 MY | 5.30 | 5.05 | 4.93 |
| F1500 MY | 5.44 | 4.04 | 34.61 |
| F1600 MY | 5.29 | 4.86 | 8.78 |
| F1700 MY | 5.62 | 6.75 | -16.72 |
| F1800 MY | 5.25 | 5.02 | 4.55 |
| F1900 MY | 5.02 | 5.30 | -5.30 |
| F2000 MY | 5.66 | 4.43 | 27.83 |
| F2100 MY | 5.21 | 4.01 | 30.01 |
| F2200 MY | 4.68 | 4.61 | 1.59 |
| F5200 FS | 5.51 | 6.52 | -15.56 |
| F5300 FS | 5.84 | 7.00 | -16.56 |
| F5400 FS | 5.14 | 4.53 | 13.55 |
| F5500 FS | 5.50 | 5.43 | 1.38 |
| F5600 FS | 5.52 | 6.28 | -12.21 |
| F5700 FS | 5.50 | 6.34 | -13.36 |

| | |
|---|---|
| Average % difference | 12.81 |

7) Overall Foreman's Skills Level

| | Overall Performance | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 3.67 | 5.33 | -31.25 |
| F1300 MY | 4.25 | 4.98 | -14.65 |
| F1400 MY | 4.33 | 5.12 | -15.52 |
| F1500 MY | 4.70 | 4.36 | 7.80 |
| F1600 MY | 4.53 | 5.08 | -10.95 |
| F1700 MY | 4.74 | 6.59 | -27.98 |
| F1800 MY | 4.60 | 6.50 | -29.27 |
| F1900 MY | 4.38 | 5.25 | -16.62 |
| F2000 MY | 4.75 | 4.80 | -1.08 |
| F2100 MY | 4.50 | 6.32 | -28.76 |
| F2200 MY | 4.08 | 4.77 | -14.45 |
| F5200 FS | 4.49 | 6.62 | -32.13 |
| F5300 FS | 4.73 | 6.92 | -31.72 |
| F5400 FS | 4.18 | 4.86 | -13.91 |
| F5500 FS | 4.57 | 6.48 | -29.44 |
| F5600 FS | 4.65 | 6.70 | -30.60 |
| F5700 FS | 4.62 | 6.54 | -29.43 |

| | |
|---|---|
| Average % difference | 21.50 |

## Appendix K: Sensitivity Analysis IV Results

1) Safety

| | Safety | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.68 | 4.00 | 16.98 |
| F1300 MY | 5.27 | 4.00 | 31.79 |
| F1400 MY | 5.45 | 4.00 | 36.19 |
| F1500 MY | 5.91 | 4.00 | 47.67 |
| F1600 MY | 5.48 | 4.00 | 36.94 |
| F1700 MY | 5.73 | 4.00 | 43.13 |
| F1800 MY | 5.87 | 4.00 | 46.65 |
| F1900 MY | 5.21 | 4.00 | 30.14 |
| F2000 MY | 5.49 | 4.00 | 37.19 |
| F2100 MY | 5.42 | 4.00 | 35.48 |
| F2200 MY | 4.94 | 4.00 | 23.56 |
| F5200 FS | 5.21 | 4.00 | 30.17 |
| F5300 FS | 5.53 | 4.00 | 38.33 |
| F5400 FS | 5.14 | 4.00 | 28.52 |
| F5500 FS | 5.81 | 4.00 | 45.28 |
| F5600 FS | 5.52 | 4.00 | 37.94 |
| F5700 FS | 5.52 | 4.00 | 38.04 |

| | |
|---|---|
| Average % difference | 35.53 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.49 | 4.00 | 12.17 |
| F1300 MY | 5.31 | 4.00 | 32.70 |
| F1400 MY | 5.33 | 4.00 | 33.19 |
| F1500 MY | 5.68 | 4.00 | 42.00 |
| F1600 MY | 5.55 | 4.00 | 38.81 |
| F1700 MY | 5.92 | 4.00 | 48.04 |
| F1800 MY | 5.35 | 4.00 | 33.85 |
| F1900 MY | 6.03 | 4.00 | 50.79 |
| F2000 MY | 6.14 | 3.00 | 104.69 |
| F2100 MY | 5.52 | 4.00 | 37.93 |
| F2200 MY | 5.13 | 4.00 | 28.25 |
| F5200 FS | 5.54 | 4.00 | 38.58 |
| F5300 FS | 5.84 | 4.00 | 45.98 |
| F5400 FS | 5.07 | 4.00 | 26.65 |
| F5500 FS | 5.35 | 4.00 | 33.83 |
| F5600 FS | 5.59 | 4.00 | 39.86 |
| F5700 FS | 5.62 | 4.00 | 40.38 |

| | |
|---|---|
| Average % difference | 40.45 |

3) Leadership and Supervision

| | leadership and Supervision | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.71 | 4.00 | 17.83 |
| F1300 MY | 5.19 | 4.00 | 29.69 |
| F1400 MY | 4.92 | 4.00 | 22.92 |
| F1500 MY | 5.67 | 4.00 | 41.81 |
| F1600 MY | 5.62 | 4.00 | 40.44 |
| F1700 MY | 6.03 | 4.00 | 50.70 |
| F1800 MY | 6.00 | 4.00 | 49.95 |
| F1900 MY | 5.51 | 4.00 | 37.79 |
| F2000 MY | 5.82 | 4.00 | 45.41 |
| F2100 MY | 5.46 | 4.00 | 36.49 |
| F2200 MY | 5.02 | 4.00 | 25.52 |
| F5200 FS | 5.61 | 4.00 | 40.33 |
| F5300 FS | 5.92 | 4.00 | 47.92 |
| F5400 FS | 4.75 | 4.00 | 18.69 |
| F5500 FS | 5.68 | 4.00 | 42.07 |
| F5600 FS | 5.72 | 4.00 | 42.97 |
| F5700 FS | 5.72 | 4.00 | 43.04 |

| | |
|---|---|
| Average % difference | 37.27 |

4) Employee Relations

| | Employee Relations | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.22 | 4.00 | 5.40 |
| F1300 MY | 4.90 | 4.00 | 22.54 |
| F1400 MY | 4.56 | 4.00 | 13.90 |
| F1500 MY | 5.77 | 4.00 | 44.25 |
| F1600 MY | 5.39 | 4.00 | 34.85 |
| F1700 MY | 5.47 | 4.00 | 36.70 |
| F1800 MY | 5.73 | 4.00 | 43.35 |
| F1900 MY | 4.92 | 4.00 | 23.04 |
| F2000 MY | 5.68 | 4.00 | 42.06 |
| F2100 MY | 5.38 | 4.00 | 34.57 |
| F2200 MY | 4.83 | 4.00 | 20.71 |
| F5200 FS | 5.21 | 4.00 | 30.14 |
| F5300 FS | 5.60 | 4.00 | 40.00 |
| F5400 FS | 4.95 | 4.00 | 23.69 |
| F5500 FS | 5.40 | 4.00 | 35.03 |
| F5600 FS | 5.57 | 4.00 | 39.33 |
| F5700 FS | 5.34 | 4.00 | 33.46 |

| | |
|---|---|
| Average % difference | 30.76 |

5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.06 | 4.00 | 1.52 |
| F1300 MY | 5.07 | 4.00 | 26.87 |
| F1400 MY | 5.33 | 4.00 | 33.35 |
| F1500 MY | 5.41 | 4.00 | 35.22 |
| F1600 MY | 5.44 | 4.00 | 36.08 |
| F1700 MY | 5.73 | 4.00 | 43.29 |
| F1800 MY | 5.39 | 4.00 | 34.85 |
| F1900 MY | 5.09 | 4.00 | 27.25 |
| F2000 MY | 5.51 | 4.00 | 37.73 |
| F2100 MY | 5.47 | 4.00 | 36.75 |
| F2200 MY | 4.91 | 4.00 | 22.81 |
| F5200 FS | 5.49 | 3.00 | 82.96 |
| F5300 FS | 5.56 | 4.00 | 38.88 |
| F5400 FS | 4.80 | 4.00 | 20.02 |
| F5500 FS | 5.35 | 4.00 | 33.82 |
| F5600 FS | 5.69 | 4.00 | 42.17 |
| F5700 FS | 5.73 | 4.00 | 43.13 |

| | |
|---|---|
| Average % difference | 35.10 |

6) Administration

| | Administration | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.56 | 3.00 | 51.88 |
| F1300 MY | 4.94 | 3.00 | 64.65 |
| F1400 MY | 5.30 | 3.00 | 76.75 |
| F1500 MY | 5.44 | 4.00 | 35.97 |
| F1600 MY | 5.29 | 4.00 | 32.21 |
| F1700 MY | 5.62 | 4.00 | 40.48 |
| F1800 MY | 5.25 | 4.00 | 31.30 |
| F1900 MY | 5.02 | 4.00 | 25.39 |
| F2000 MY | 5.66 | 3.00 | 88.63 |
| F2100 MY | 5.21 | 4.00 | 30.17 |
| F2200 MY | 4.68 | 3.00 | 56.10 |
| F5200 FS | 5.51 | 4.00 | 37.67 |
| F5300 FS | 5.84 | 4.00 | 46.02 |
| F5400 FS | 5.14 | 4.00 | 28.60 |
| F5500 FS | 5.50 | 4.00 | 37.58 |
| F5600 FS | 5.52 | 4.00 | 37.94 |
| F5700 FS | 5.50 | 4.00 | 37.42 |

| | |
|---|---|
| Average % difference | 44.63 |

7) Overall Foreman's Skills Level

| | Overall Performance | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.45 | 3.33 | 33.56 |
| F1300 MY | 5.11 | 3.33 | 53.42 |
| F1400 MY | 5.15 | 3.33 | 54.58 |
| F1500 MY | 5.65 | 4.00 | 41.15 |
| F1600 MY | 5.46 | 4.00 | 36.56 |
| F1700 MY | 5.75 | 4.00 | 43.72 |
| F1800 MY | 5.60 | 4.00 | 39.99 |
| F1900 MY | 5.30 | 4.00 | 32.40 |
| F2000 MY | 5.72 | 3.33 | 71.48 |
| F2100 MY | 5.41 | 4.00 | 35.23 |
| F2200 MY | 4.92 | 3.33 | 47.73 |
| F5200 FS | 5.43 | 3.33 | 62.99 |
| F5300 FS | 5.71 | 4.00 | 42.86 |
| F5400 FS | 4.97 | 4.00 | 24.36 |
| F5500 FS | 5.52 | 4.00 | 37.94 |
| F5600 FS | 5.60 | 4.00 | 40.04 |
| F5700 FS | 5.57 | 4.00 | 39.24 |

| | |
|---|---|
| Average % difference | 43.37 |

## Appendix L: Sensitivity Analysis V Results

1) Safety

| | Safety | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.68 | 5.25 | -10.87 |
| F1300 MY | 5.27 | 5.25 | 0.41 |
| F1400 MY | 5.45 | 5.25 | 3.76 |
| F1500 MY | 5.91 | 6.50 | -9.13 |
| F1600 MY | 5.48 | 5.25 | 4.33 |
| F1700 MY | 5.73 | 5.56 | 3.01 |
| F1800 MY | 5.87 | 6.02 | -2.49 |
| F1900 MY | 5.21 | 5.25 | -0.84 |
| F2000 MY | 5.49 | 5.25 | 4.52 |
| F2100 MY | 5.42 | 6.36 | -14.77 |
| F2200 MY | 4.94 | 5.25 | -5.86 |
| F5200 FS | 5.21 | 5.25 | -0.83 |
| F5300 FS | 5.53 | 5.98 | -7.54 |
| F5400 FS | 5.14 | 5.25 | -2.08 |
| F5500 FS | 5.81 | 6.50 | -10.59 |
| F5600 FS | 5.52 | 5.90 | -6.50 |
| F5700 FS | 5.52 | 5.33 | 3.54 |

| | |
|---|---|
| Average % difference | 5.36 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.49 | 4.00 | 12.17 |
| F1300 MY | 5.31 | 5.29 | 0.30 |
| F1400 MY | 5.33 | 5.25 | 1.48 |
| F1500 MY | 5.68 | 5.67 | 0.24 |
| F1600 MY | 5.55 | 5.67 | -2.01 |
| F1700 MY | 5.92 | 6.50 | -8.90 |
| F1800 MY | 5.35 | 5.49 | -2.44 |
| F1900 MY | 6.03 | 6.50 | -7.21 |
| F2000 MY | 6.14 | 6.50 | -5.53 |
| F2100 MY | 5.52 | 6.25 | -11.75 |
| F2200 MY | 5.13 | 5.25 | -2.29 |
| F5200 FS | 5.54 | 6.50 | -14.72 |
| F5300 FS | 5.84 | 6.50 | -10.17 |
| F5400 FS | 5.07 | 6.05 | -16.25 |
| F5500 FS | 5.35 | 6.17 | -13.29 |
| F5600 FS | 5.59 | 6.27 | -10.81 |
| F5700 FS | 5.62 | 6.50 | -13.62 |

| | |
|---|---|
| Average % difference | 7.83 |

3) Leadership and Supervision

| | leadership and Supervision | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.71 | 4.95 | -4.78 |
| F1300 MY | 5.19 | 5.25 | -1.19 |
| F1400 MY | 4.92 | 5.25 | -6.35 |
| F1500 MY | 5.67 | 5.25 | 8.04 |
| F1600 MY | 5.62 | 5.25 | 7.00 |
| F1700 MY | 6.03 | 6.15 | -1.92 |
| F1800 MY | 6.00 | 5.50 | 9.03 |
| F1900 MY | 5.51 | 5.25 | 4.98 |
| F2000 MY | 5.82 | 5.55 | 4.71 |
| F2100 MY | 5.46 | 5.25 | 3.99 |
| F2200 MY | 5.02 | 5.25 | -4.37 |
| F5200 FS | 5.61 | 6.13 | -8.39 |
| F5300 FS | 5.92 | 6.50 | -8.97 |
| F5400 FS | 4.75 | 4.85 | -2.11 |
| F5500 FS | 5.68 | 5.70 | -0.31 |
| F5600 FS | 5.72 | 6.15 | -6.95 |
| F5700 FS | 5.72 | 5.25 | 8.98 |

| | |
|---|---|
| Average % difference | 5.42 |

4) Employee Relations

| | Employee Relations | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.22 | 4.02 | 4.75 |
| F1300 MY | 4.90 | 4.28 | 14.58 |
| F1400 MY | 4.56 | 4.43 | 2.86 |
| F1500 MY | 5.77 | 5.25 | 9.90 |
| F1600 MY | 5.39 | 5.08 | 6.16 |
| F1700 MY | 5.47 | 5.41 | 1.02 |
| F1800 MY | 5.73 | 5.64 | 1.68 |
| F1900 MY | 4.92 | 5.15 | -4.51 |
| F2000 MY | 5.68 | 5.15 | 10.34 |
| F2100 MY | 5.38 | 5.25 | 2.53 |
| F2200 MY | 4.83 | 4.66 | 3.54 |
| F5200 FS | 5.21 | 5.55 | -6.25 |
| F5300 FS | 5.60 | 5.25 | 6.67 |
| F5400 FS | 4.95 | 5.25 | -5.76 |
| F5500 FS | 5.40 | 5.56 | -2.81 |
| F5600 FS | 5.57 | 5.97 | -6.62 |
| F5700 FS | 5.34 | 5.25 | 1.68 |

| | |
|---|---|
| Average % difference | 5.39 |

### 5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.06 | 3.89 | 4.35 |
| F1300 MY | 5.07 | 5.25 | -3.34 |
| F1400 MY | 5.33 | 5.25 | 1.60 |
| F1500 MY | 5.41 | 5.20 | 4.02 |
| F1600 MY | 5.44 | 5.82 | -6.44 |
| F1700 MY | 5.73 | 6.22 | -7.89 |
| F1800 MY | 5.39 | 5.25 | 2.74 |
| F1900 MY | 5.09 | 5.25 | -3.05 |
| F2000 MY | 5.51 | 4.36 | 26.49 |
| F2100 MY | 5.47 | 5.25 | 4.19 |
| F2200 MY | 4.91 | 5.21 | -5.77 |
| F5200 FS | 5.49 | 6.50 | -15.56 |
| F5300 FS | 5.56 | 5.66 | -1.77 |
| F5400 FS | 4.80 | 5.25 | -8.56 |
| F5500 FS | 5.35 | 5.25 | 1.96 |
| F5600 FS | 5.69 | 6.50 | -12.51 |
| F5700 FS | 5.73 | 5.29 | 8.32 |

| | |
|---|---|
| Average % difference | 6.97 |

### 6) Administration

| | Administration | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.56 | 4.74 | -3.91 |
| F1300 MY | 4.94 | 5.25 | -5.91 |
| F1400 MY | 5.30 | 5.48 | -3.22 |
| F1500 MY | 5.44 | 5.25 | 3.51 |
| F1600 MY | 5.29 | 5.26 | 0.54 |
| F1700 MY | 5.62 | 5.49 | 2.31 |
| F1800 MY | 5.25 | 5.25 | 0.04 |
| F1900 MY | 5.02 | 5.25 | -4.46 |
| F2000 MY | 5.66 | 5.54 | 2.17 |
| F2100 MY | 5.21 | 4.95 | 5.19 |
| F2200 MY | 4.68 | 4.84 | -3.33 |
| F5200 FS | 5.51 | 5.98 | -7.86 |
| F5300 FS | 5.84 | 5.93 | -1.51 |
| F5400 FS | 5.14 | 5.25 | -2.02 |
| F5500 FS | 5.50 | 5.25 | 4.83 |
| F5600 FS | 5.52 | 6.00 | -8.04 |
| F5700 FS | 5.50 | 5.93 | -7.32 |

| | |
|---|---|
| Average % difference | 3.89 |

7) Overall Foreman's Skills Level

| | Overall Performance | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.45 | 4.43 | 0.41 |
| F1300 MY | 5.11 | 5.17 | -1.02 |
| F1400 MY | 5.15 | 5.17 | -0.37 |
| F1500 MY | 5.65 | 5.45 | 3.60 |
| F1600 MY | 5.46 | 5.17 | 5.72 |
| F1700 MY | 5.75 | 5.25 | 9.41 |
| F1800 MY | 5.60 | 5.17 | 8.38 |
| F1900 MY | 5.30 | 5.17 | 2.50 |
| F2000 MY | 5.72 | 5.46 | 4.75 |
| F2100 MY | 5.41 | 5.17 | 4.70 |
| F2200 MY | 4.92 | 5.17 | -4.78 |
| F5200 FS | 5.43 | 5.67 | -4.35 |
| F5300 FS | 5.71 | 5.55 | 2.98 |
| F5400 FS | 4.97 | 5.17 | -3.72 |
| F5500 FS | 5.52 | 5.17 | 6.79 |
| F5600 FS | 5.60 | 5.31 | 5.42 |
| F5700 FS | 5.57 | 5.17 | 7.80 |

| | |
|---|---|
| Average % difference | 4.51 |

# Appendix M: Sensitivity Analysis VI Results

1) Safety

| | Safety | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.68 | 4.00 | 16.98 |
| F1300 MY | 5.27 | 4.00 | 31.79 |
| F1400 MY | 5.45 | 6.50 | -16.19 |
| F1500 MY | 5.91 | 6.50 | -9.13 |
| F1600 MY | 5.48 | 6.50 | -15.73 |
| F1700 MY | 5.73 | 6.50 | -11.92 |
| F1800 MY | 5.87 | 6.50 | -9.75 |
| F1900 MY | 5.21 | 6.50 | -19.91 |
| F2000 MY | 5.49 | 4.00 | 37.19 |
| F2100 MY | 5.42 | 6.50 | -16.63 |
| F2200 MY | 4.94 | 6.50 | -23.96 |
| F5200 FS | 5.21 | 6.50 | -19.90 |
| F5300 FS | 5.53 | 6.50 | -14.88 |
| F5400 FS | 5.14 | 6.50 | -20.91 |
| F5500 FS | 5.81 | 6.50 | -10.59 |
| F5600 FS | 5.52 | 6.50 | -15.11 |
| F5700 FS | 5.52 | 6.50 | -15.05 |

| | |
|---|---|
| Average % difference | 17.98 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.49 | 4.00 | 12.17 |
| F1300 MY | 5.31 | 4.00 | 32.70 |
| F1400 MY | 5.33 | 6.50 | -18.04 |
| F1500 MY | 5.68 | 4.00 | 42.00 |
| F1600 MY | 5.55 | 4.00 | 38.81 |
| F1700 MY | 5.92 | 6.50 | -8.90 |
| F1800 MY | 5.35 | 6.50 | -17.63 |
| F1900 MY | 6.03 | 6.50 | -7.21 |
| F2000 MY | 6.14 | 6.50 | -5.53 |
| F2100 MY | 5.52 | 6.50 | -15.12 |
| F2200 MY | 5.13 | 4.00 | 28.25 |
| F5200 FS | 5.54 | 6.50 | -14.72 |
| F5300 FS | 5.84 | 6.50 | -10.17 |
| F5400 FS | 5.07 | 6.50 | -22.06 |
| F5500 FS | 5.35 | 6.50 | -17.64 |
| F5600 FS | 5.59 | 6.50 | -13.93 |
| F5700 FS | 5.62 | 6.50 | -13.62 |

| | |
|---|---|
| Average % difference | 18.73 |

### 3) Leadership and Supervision

| | leadership and Supervision | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.71 | 4.00 | 17.83 |
| F1300 MY | 5.19 | 4.00 | 29.69 |
| F1400 MY | 4.92 | 6.50 | -24.36 |
| F1500 MY | 5.67 | 4.00 | 41.81 |
| F1600 MY | 5.62 | 4.00 | 40.44 |
| F1700 MY | 6.03 | 6.50 | -7.26 |
| F1800 MY | 6.00 | 6.50 | -7.72 |
| F1900 MY | 5.51 | 6.50 | -15.21 |
| F2000 MY | 5.82 | 4.00 | 45.41 |
| F2100 MY | 5.46 | 6.50 | -16.01 |
| F2200 MY | 5.02 | 6.50 | -22.76 |
| F5200 FS | 5.61 | 6.50 | -13.64 |
| F5300 FS | 5.88 | 6.50 | -9.61 |
| F5400 FS | 4.75 | 4.00 | 18.69 |
| F5500 FS | 5.68 | 6.50 | -12.57 |
| F5600 FS | 5.72 | 6.50 | -12.02 |
| F5700 FS | 5.72 | 6.50 | -11.97 |

| | |
|---|---|
| Average % difference | 20.41 |

### 4) Employee Relations

| | Employee Relations | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.22 | 4.00 | 5.40 |
| F1300 MY | 4.90 | 4.00 | 22.54 |
| F1400 MY | 4.56 | 4.00 | 13.90 |
| F1500 MY | 5.77 | 4.00 | 44.25 |
| F1600 MY | 5.39 | 4.00 | 34.85 |
| F1700 MY | 5.47 | 6.50 | -15.88 |
| F1800 MY | 5.73 | 6.50 | -11.78 |
| F1900 MY | 4.92 | 4.00 | 23.04 |
| F2000 MY | 5.68 | 4.00 | 42.06 |
| F2100 MY | 5.38 | 6.50 | -17.19 |
| F2200 MY | 4.83 | 4.00 | 20.71 |
| F5200 FS | 5.21 | 6.50 | -19.91 |
| F5300 FS | 5.60 | 6.50 | -13.85 |
| F5400 FS | 4.95 | 4.00 | 23.69 |
| F5500 FS | 5.40 | 6.50 | -16.90 |
| F5600 FS | 5.57 | 6.50 | -14.26 |
| F5700 FS | 5.34 | 6.50 | -17.87 |

| | |
|---|---|
| Average % difference | 21.06 |

5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.06 | 4.00 | 1.52 |
| F1300 MY | 5.07 | 6.50 | -21.93 |
| F1400 MY | 5.33 | 6.50 | -17.94 |
| F1500 MY | 5.41 | 4.00 | 35.22 |
| F1600 MY | 5.44 | 6.50 | -16.26 |
| F1700 MY | 5.73 | 6.50 | -11.82 |
| F1800 MY | 5.39 | 6.50 | -17.02 |
| F1900 MY | 5.09 | 6.50 | -21.69 |
| F2000 MY | 5.51 | 4.00 | 37.73 |
| F2100 MY | 5.47 | 6.50 | -15.85 |
| F2200 MY | 4.91 | 4.00 | 22.81 |
| F5200 FS | 5.49 | 6.50 | -15.56 |
| F5300 FS | 5.56 | 6.50 | -14.53 |
| F5400 FS | 4.80 | 4.00 | 20.02 |
| F5500 FS | 5.35 | 6.50 | -17.65 |
| F5600 FS | 5.69 | 6.50 | -12.51 |
| F5700 FS | 5.73 | 6.50 | -11.92 |

| | |
|---|---|
| Average % difference | 18.35 |

6) Administration

| | Administration | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.56 | 4.00 | 13.91 |
| F1300 MY | 4.94 | 6.50 | -24.01 |
| F1400 MY | 5.30 | 6.50 | -18.42 |
| F1500 MY | 5.44 | 4.00 | 35.97 |
| F1600 MY | 5.29 | 6.50 | -18.64 |
| F1700 MY | 5.62 | 6.50 | -13.55 |
| F1800 MY | 5.25 | 6.50 | -19.20 |
| F1900 MY | 5.02 | 6.50 | -22.84 |
| F2000 MY | 5.66 | 4.00 | 41.47 |
| F2100 MY | 5.21 | 4.00 | 30.17 |
| F2200 MY | 4.68 | 4.00 | 17.08 |
| F5200 FS | 5.51 | 4.00 | 37.67 |
| F5300 FS | 5.84 | 6.50 | -10.14 |
| F5400 FS | 5.14 | 4.00 | 28.60 |
| F5500 FS | 5.50 | 6.50 | -15.33 |
| F5600 FS | 5.52 | 6.50 | -15.11 |
| F5700 FS | 5.50 | 6.50 | -15.44 |

| | |
|---|---|
| Average % difference | 22.21 |

## 7) Overall Foreman's Skills Level

| Foreman Code | Overall Performance | | |
|---|---|---|---|
| | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.45 | 4.00 | 11.30 |
| F1300 MY | 5.11 | 4.00 | 27.85 |
| F1400 MY | 5.15 | 5.00 | 2.95 |
| F1500 MY | 5.65 | 4.00 | 41.15 |
| F1600 MY | 5.46 | 4.00 | 36.56 |
| F1700 MY | 5.75 | 6.50 | -11.56 |
| F1800 MY | 5.60 | 6.50 | -13.85 |
| F1900 MY | 5.30 | 6.50 | -18.52 |
| F2000 MY | 5.72 | 4.00 | 42.90 |
| F2100 MY | 5.41 | 6.50 | -16.78 |
| F2200 MY | 4.92 | 4.00 | 22.99 |
| F5200 FS | 5.43 | 6.50 | -16.50 |
| F5300 FS | 5.71 | 6.50 | -12.20 |
| F5400 FS | 4.97 | 4.00 | 24.36 |
| F5500 FS | 5.52 | 6.50 | -15.12 |
| F5600 FS | 5.60 | 6.50 | -13.82 |
| F5700 FS | 5.57 | 6.50 | -14.31 |

| Average % difference | 20.16 |
|---|---|

## Appendix N: Sensitivity Analysis VII Results

1) Safety

| | Safety | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.68 | 4.88 | -4.13 |
| F1300 MY | 5.27 | 4.86 | 8.53 |
| F1400 MY | 5.45 | 5.10 | 6.92 |
| F1500 MY | 5.91 | 5.92 | -0.18 |
| F1600 MY | 5.48 | 5.17 | 5.95 |
| F1700 MY | 5.73 | 5.50 | 4.11 |
| F1800 MY | 5.87 | 5.71 | 2.71 |
| F1900 MY | 5.21 | 5.07 | 2.66 |
| F2000 MY | 5.49 | 4.90 | 12.06 |
| F2100 MY | 5.42 | 5.72 | -5.24 |
| F2200 MY | 4.94 | 4.97 | -0.52 |
| F5200 FS | 5.21 | 5.28 | -1.35 |
| F5300 FS | 5.53 | 5.64 | -1.95 |
| F5400 FS | 5.14 | 5.10 | 0.90 |
| F5500 FS | 5.81 | 5.92 | -1.78 |
| F5600 FS | 5.52 | 5.44 | 1.41 |
| F5700 FS | 5.52 | 5.44 | 1.48 |

| | |
|---|---|
| Average % difference | 3.64 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.49 | 4.00 | 12.16 |
| F1300 MY | 5.31 | 4.96 | 7.05 |
| F1400 MY | 5.33 | 5.12 | 4.09 |
| F1500 MY | 5.68 | 4.96 | 14.56 |
| F1600 MY | 5.55 | 4.96 | 11.98 |
| F1700 MY | 5.92 | 5.92 | 0.07 |
| F1800 MY | 5.35 | 5.40 | -0.84 |
| F1900 MY | 6.03 | 5.92 | 1.94 |
| F2000 MY | 6.14 | 5.92 | 3.78 |
| F2100 MY | 5.52 | 5.57 | -0.97 |
| F2200 MY | 5.13 | 4.79 | 7.10 |
| F5200 FS | 5.54 | 5.92 | -6.31 |
| F5300 FS | 5.84 | 5.92 | -1.31 |
| F5400 FS | 5.07 | 5.37 | -5.65 |
| F5500 FS | 5.35 | 5.48 | -2.39 |
| F5600 FS | 5.59 | 5.64 | -0.76 |
| F5700 FS | 5.62 | 5.92 | -5.10 |

| | |
|---|---|
| Average % difference | 5.06 |

### 3) Leadership and Supervision

| | **leadership and Supervision** | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.71 | 4.61 | 2.18 |
| F1300 MY | 5.19 | 4.72 | 9.94 |
| F1400 MY | 4.92 | 5.02 | -2.05 |
| F1500 MY | 5.67 | 5.25 | 8.04 |
| F1600 MY | 5.62 | 4.96 | 13.29 |
| F1700 MY | 6.03 | 5.51 | 9.43 |
| F1800 MY | 6.00 | 5.53 | 8.39 |
| F1900 MY | 5.51 | 5.17 | 6.65 |
| F2000 MY | 5.82 | 5.45 | 6.72 |
| F2100 MY | 5.46 | 5.39 | 1.25 |
| F2200 MY | 5.02 | 4.96 | 1.16 |
| F5200 FS | 5.61 | 5.73 | -2.01 |
| F5300 FS | 5.92 | 5.92 | 0.00 |
| F5400 FS | 4.75 | 4.61 | 3.06 |
| F5500 FS | 5.68 | 5.51 | 3.15 |
| F5600 FS | 5.72 | 5.44 | 5.10 |
| F5700 FS | 5.72 | 5.44 | 5.15 |

| | |
|---|---|
| Average % difference | 5.15 |

### 4) Employee Relations

| | **Employee Relations** | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.22 | 4.01 | 5.24 |
| F1300 MY | 4.90 | 4.30 | 14.00 |
| F1400 MY | 4.56 | 4.46 | 2.05 |
| F1500 MY | 5.77 | 4.99 | 15.63 |
| F1600 MY | 5.39 | 5.05 | 6.82 |
| F1700 MY | 5.47 | 4.96 | 10.26 |
| F1800 MY | 5.73 | 5.56 | 3.06 |
| F1900 MY | 4.92 | 4.72 | 4.29 |
| F2000 MY | 5.68 | 5.15 | 10.34 |
| F2100 MY | 5.38 | 5.38 | 0.04 |
| F2200 MY | 4.83 | 4.77 | 1.21 |
| F5200 FS | 5.21 | 5.25 | -0.91 |
| F5300 FS | 5.60 | 5.28 | 6.08 |
| F5400 FS | 4.95 | 4.86 | 1.82 |
| F5500 FS | 5.40 | 5.41 | -0.09 |
| F5600 FS | 5.57 | 5.38 | 3.68 |
| F5700 FS | 5.34 | 5.25 | 1.61 |

| | |
|---|---|
| Average % difference | 5.12 |

5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.06 | 3.84 | 5.67 |
| F1300 MY | 5.07 | 5.11 | -0.67 |
| F1400 MY | 5.33 | 4.96 | 7.56 |
| F1500 MY | 5.41 | 4.40 | 22.99 |
| F1600 MY | 5.44 | 5.10 | 6.81 |
| F1700 MY | 5.73 | 5.56 | 3.15 |
| F1800 MY | 5.39 | 5.28 | 2.18 |
| F1900 MY | 5.09 | 5.01 | 1.50 |
| F2000 MY | 5.51 | 4.34 | 27.03 |
| F2100 MY | 5.47 | 5.42 | 0.94 |
| F2200 MY | 4.91 | 4.35 | 12.95 |
| F5200 FS | 5.49 | 5.92 | -7.23 |
| F5300 FS | 5.56 | 5.57 | -0.17 |
| F5400 FS | 4.80 | 4.77 | 0.65 |
| F5500 FS | 5.35 | 5.16 | 3.69 |
| F5600 FS | 5.69 | 5.92 | -3.89 |
| F5700 FS | 5.73 | 5.60 | 2.28 |

| | |
|---|---|
| Average % difference | 6.43 |

6) Administration

| | Administration | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.56 | 4.50 | 1.26 |
| F1300 MY | 4.94 | 4.96 | -0.39 |
| F1400 MY | 5.30 | 4.96 | 6.92 |
| F1500 MY | 5.44 | 5.15 | 5.61 |
| F1600 MY | 5.29 | 4.96 | 6.64 |
| F1700 MY | 5.62 | 5.41 | 3.88 |
| F1800 MY | 5.25 | 4.96 | 5.91 |
| F1900 MY | 5.02 | 4.99 | 0.43 |
| F2000 MY | 5.66 | 5.25 | 7.79 |
| F2100 MY | 5.21 | 5.22 | -0.25 |
| F2200 MY | 4.68 | 4.87 | -3.81 |
| F5200 FS | 5.51 | 5.39 | 2.23 |
| F5300 FS | 5.84 | 5.92 | -1.29 |
| F5400 FS | 5.14 | 4.82 | 6.67 |
| F5500 FS | 5.50 | 5.45 | 0.98 |
| F5600 FS | 5.52 | 5.28 | 4.53 |
| F5700 FS | 5.50 | 5.28 | 4.13 |

| | |
|---|---|
| Average % difference | 3.69 |

7) Overall Foreman's Skills Level

| | Overall Performance | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.45 | 4.33 | 2.92 |
| F1300 MY | 5.11 | 5.19 | -1.46 |
| F1400 MY | 5.15 | 5.28 | -2.55 |
| F1500 MY | 5.65 | 4.88 | 15.78 |
| F1600 MY | 5.46 | 5.24 | 4.28 |
| F1700 MY | 5.75 | 5.73 | 0.35 |
| F1800 MY | 5.60 | 5.71 | -1.88 |
| F1900 MY | 5.30 | 5.33 | -0.60 |
| F2000 MY | 5.72 | 5.13 | 11.41 |
| F2100 MY | 5.41 | 5.61 | -3.53 |
| F2200 MY | 4.92 | 5.13 | -4.05 |
| F5200 FS | 5.43 | 5.84 | -7.08 |
| F5300 FS | 5.71 | 6.08 | -6.00 |
| F5400 FS | 4.97 | 5.16 | -3.59 |
| F5500 FS | 5.52 | 5.71 | -3.29 |
| F5600 FS | 5.60 | 5.70 | -1.66 |
| F5700 FS | 5.57 | 5.70 | -2.22 |

| | |
|---|---|
| Average % difference | 4.27 |

# Appendix O: Sensitivity Analysis VIII Results

1) Safety

| | Safety | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.68 | 5.15 | -9.12 |
| F1300 MY | 5.27 | 5.12 | 3.00 |
| F1400 MY | 5.45 | 5.43 | 0.35 |
| F1500 MY | 5.91 | 6.50 | -9.13 |
| F1600 MY | 5.48 | 5.53 | -0.88 |
| F1700 MY | 5.73 | 5.96 | -3.86 |
| F1800 MY | 5.87 | 6.23 | -5.87 |
| F1900 MY | 5.21 | 5.40 | -3.54 |
| F2000 MY | 5.49 | 5.17 | 6.14 |
| F2100 MY | 5.42 | 6.24 | -13.17 |
| F2200 MY | 4.94 | 5.26 | -6.09 |
| F5200 FS | 5.21 | 5.67 | -8.12 |
| F5300 FS | 5.53 | 6.14 | -9.93 |
| F5400 FS | 5.14 | 5.43 | -5.30 |
| F5500 FS | 5.81 | 6.50 | -10.59 |
| F5600 FS | 5.52 | 5.88 | -6.15 |
| F5700 FS | 5.52 | 5.88 | -6.09 |

| | |
|---|---|
| Average % difference | 6.31 |

2) QA/QC

| | QA/QC | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.49 | 4.00 | 12.17 |
| F1300 MY | 5.31 | 5.25 | 1.11 |
| F1400 MY | 5.33 | 5.46 | -2.40 |
| F1500 MY | 5.68 | 5.25 | 8.19 |
| F1600 MY | 5.55 | 5.25 | 5.76 |
| F1700 MY | 5.92 | 6.50 | -8.90 |
| F1800 MY | 5.35 | 5.82 | -8.08 |
| F1900 MY | 6.03 | 6.50 | -7.21 |
| F2000 MY | 6.14 | 6.50 | -5.53 |
| F2100 MY | 5.52 | 6.05 | -8.79 |
| F2200 MY | 5.13 | 5.03 | 1.99 |
| F5200 FS | 5.54 | 6.50 | -14.72 |
| F5300 FS | 5.84 | 6.50 | -10.17 |
| F5400 FS | 5.07 | 5.79 | -12.44 |
| F5500 FS | 5.35 | 5.94 | -9.82 |
| F5600 FS | 5.59 | 6.13 | -8.81 |
| F5700 FS | 5.62 | 6.50 | -13.62 |

| | |
|---|---|
| Average % difference | 8.22 |

3) Leadership and Supervision

| | leadership and Supervision | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.71 | 4.80 | -1.79 |
| F1300 MY | 5.19 | 4.94 | 5.07 |
| F1400 MY | 4.92 | 5.33 | -7.75 |
| F1500 MY | 5.67 | 5.00 | 13.38 |
| F1600 MY | 5.62 | 5.25 | 7.00 |
| F1700 MY | 6.03 | 5.97 | 1.01 |
| F1800 MY | 6.00 | 5.88 | 2.02 |
| F1900 MY | 5.51 | 5.52 | -0.21 |
| F2000 MY | 5.82 | 5.10 | 14.15 |
| F2100 MY | 5.46 | 5.82 | -6.11 |
| F2200 MY | 5.02 | 5.26 | -4.48 |
| F5200 FS | 5.61 | 6.25 | -10.25 |
| F5300 FS | 5.92 | 6.50 | -8.97 |
| F5400 FS | 4.75 | 4.79 | -0.91 |
| F5500 FS | 5.68 | 5.97 | -4.78 |
| F5600 FS | 5.72 | 5.88 | -2.73 |
| F5700 FS | 5.72 | 5.88 | -2.68 |

| | |
|---|---|
| Average % difference | 5.49 |

4) Employee Relations

| | Employee Relations | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.22 | 4.01 | 5.19 |
| F1300 MY | 4.90 | 4.39 | 11.64 |
| F1400 MY | 4.56 | 4.61 | -1.08 |
| F1500 MY | 5.77 | 4.16 | 38.62 |
| F1600 MY | 5.39 | 4.84 | 11.54 |
| F1700 MY | 5.47 | 5.25 | 4.13 |
| F1800 MY | 5.73 | 6.04 | -5.06 |
| F1900 MY | 4.92 | 4.94 | -0.33 |
| F2000 MY | 5.68 | 4.87 | 16.77 |
| F2100 MY | 5.38 | 5.80 | -7.21 |
| F2200 MY | 4.83 | 5.01 | -3.53 |
| F5200 FS | 5.21 | 5.63 | -7.62 |
| F5300 FS | 5.60 | 5.67 | -1.19 |
| F5400 FS | 4.95 | 5.12 | -3.38 |
| F5500 FS | 5.40 | 5.83 | -7.42 |
| F5600 FS | 5.57 | 5.79 | -3.81 |
| F5700 FS | 5.34 | 5.63 | -5.26 |

| | |
|---|---|
| Average % difference | 7.87 |

5) Planning and Scheduling

| | Planning and Scheduling | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.06 | 3.80 | 7.00 |
| F1300 MY | 5.07 | 5.45 | -6.82 |
| F1400 MY | 5.33 | 5.25 | 1.58 |
| F1500 MY | 5.41 | 4.52 | 19.69 |
| F1600 MY | 5.44 | 5.43 | 0.25 |
| F1700 MY | 5.73 | 6.03 | -4.95 |
| F1800 MY | 5.39 | 5.67 | -4.83 |
| F1900 MY | 5.09 | 5.32 | -4.39 |
| F2000 MY | 5.51 | 4.44 | 24.10 |
| F2100 MY | 5.47 | 5.85 | -6.51 |
| F2200 MY | 4.91 | 4.46 | 10.26 |
| F5200 FS | 5.49 | 6.50 | -15.56 |
| F5300 FS | 5.56 | 6.04 | -8.04 |
| F5400 FS | 4.80 | 5.00 | -4.08 |
| F5500 FS | 5.35 | 5.52 | -2.95 |
| F5600 FS | 5.69 | 6.50 | -12.51 |
| F5700 FS | 5.73 | 6.08 | -5.89 |

| | |
|---|---|
| Average % difference | 8.20 |

6) Administration

| | Administration | | |
|---|---|---|---|
| Foreman Code | Predicted Output | Actual Output | % difference |
| F1200 MY | 4.56 | 4.65 | -2.04 |
| F1300 MY | 4.94 | 5.25 | -5.93 |
| F1400 MY | 5.30 | 5.25 | 0.98 |
| F1500 MY | 5.44 | 4.37 | 24.50 |
| F1600 MY | 5.29 | 5.25 | 0.71 |
| F1700 MY | 5.62 | 5.84 | -3.75 |
| F1800 MY | 5.25 | 5.25 | 0.02 |
| F1900 MY | 5.02 | 5.30 | -5.30 |
| F2000 MY | 5.66 | 4.94 | 14.57 |
| F2100 MY | 5.21 | 4.39 | 18.61 |
| F2200 MY | 4.68 | 5.13 | -8.76 |
| F5200 FS | 5.51 | 5.81 | -5.19 |
| F5300 FS | 5.84 | 6.50 | -10.14 |
| F5400 FS | 5.14 | 5.07 | 1.40 |
| F5500 FS | 5.50 | 5.39 | 2.16 |
| F5600 FS | 5.52 | 5.67 | -2.64 |
| F5700 FS | 5.50 | 5.67 | -3.02 |

| | |
|---|---|
| Average % difference | 6.46 |

7) Overall Foreman's Skills Level

| | Overall Performance | | |
|---|---|---|---|
| **Foreman Code** | **Predicted Output** | **Actual Output** | **% difference** |
| F1200 MY | 4.45 | 4.32 | 2.95 |
| F1300 MY | 5.11 | 5.12 | -0.04 |
| F1400 MY | 5.15 | 5.22 | -1.30 |
| F1500 MY | 5.65 | 4.80 | 17.61 |
| F1600 MY | 5.46 | 5.17 | 5.72 |
| F1700 MY | 5.75 | 5.75 | 0.03 |
| F1800 MY | 5.60 | 5.69 | -1.55 |
| F1900 MY | 5.30 | 5.26 | 0.59 |
| F2000 [illegible]Y | 5.72 | 5.05 | 13.17 |
| F2100 MY | 5.41 | 5.59 | -3.26 |
| F2200 MY | 4.92 | 5.05 | -2.55 |
| F5200 FS | 5.43 | 5.90 | -7.96 |
| F5300 FS | 5.71 | 6.25 | -8.58 |
| F5400 FS | 4.97 | 5.08 | -2.12 |
| F5500 FS | 5.52 | 5.72 | -3.47 |
| F5600 FS | 5.60 | 5.70 | -1.81 |
| F5700 FS | 5.57 | 5.70 | -2.36 |

| | |
|---|---|
| Average % difference | 4.42 |